







# MANUAL FOR WATER PLANT OPERATORS

by

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1945

CHEMICAL PUBLISHING COMPANY, INC.

BROOKLYN

NEW YORK



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1945

THE CHEMICAL PUBLISHING CO., INC.  
BROOKLYN N. Y.

Second Printing, April, 1946

## PREFACE

*To-morrow's forgotten man stopped learning yesterday*

The object of this manual is to provide a practical text for study by operators of water supply systems in preparation for their certification examinations, and a reference for their consultation in times of difficulty or doubt. This publication is an outgrowth of the traveling school for water and sewerage system operators, conducted by the Louisiana State Department of Education, Trade and Industrial Education Division. The primary intention of this manual was to furnish a text for individual study during the intervals between visits and classes held by the Sectional School on Water Supply and Sewerage. While its method of presentation has been accommodated to the grasp of men without more than grammar-grade schooling, the contents of this book reach widely into the broad subject matter which a truly competent operator should know. So far as possible the method of treatment is intimate and definitive, rather than hazy or inconclusive.

A special effort has been made to include the latest developments in water technology, so that this compilation represents an accurate, comprehensive picture of current operating practice, told in simple style. Some consideration is given to the subject of public relations, and to the personal advancement of the operator. A chapter is devoted to the subject of operation during various emergencies with the purpose that it will furnish a basis on which each operator can carefully preview and prepare for his own course of action in advance of actual distress.

The author has drawn as widely as possible from other sources in developing the various topics in the following pages. To give due acknowledgment to so considerable a number of

authorities, either by direct mention or terminal references, is hardly possible in a work of this sort. For carefully reviewing the manuscript, indebtedness is acknowledged to Mr. John H. O'Neill, Sanitary Engineer, Louisiana State Department of Health.

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## CHAPTER 1

### GENERAL CONSIDERATIONS

**Broad Fields of Usefulness of Water.** Water is a biological necessity for all forms of plant and animal life; for humans, the need for water extends into the whole pattern of daily affairs. Some of the principal activities in which water is essential are enumerated below.

Uses of direct concern to public supplies:

Alimentation (cooking, eating, drinking and other domestic uses, etc.)

Waste disposal (sewage, industrial wastes, brines)

Fire protection

Industry (steam generation, material)

Some important uses not in the field of public water supply:

Irrigation

Transportation

Drainage

Power

This list is by no means exhaustive; each field of application in itself offers wide scope for individual consideration. Only the aspects connected with public water supply can be discussed at length in this manual.

**Source of Water; the Hydrological Cycle.** As water exists everywhere in nature, it assumes many varied and familiar forms. Permeating the atmosphere as a gas or mist, commonplace states are water vapor and clouds. Water vapor may condense to a liquid or solid according to temperature conditions in the form of dew or frost; or it may precipitate as rain,

snow or hail, dependent on atmospheric circumstances. Freezing of large volumes causes solidification as ice.

Since water assumes so many forms, a variety of fates follow its precipitation as rainfall upon the earth's surface. Portions loosely held by topsoil as well as droplets and films on vegetation or solid objects evaporate into the atmosphere. Vegetation also returns moisture to the air by the process of breathing or transpiration. Most of the rainfall usually drains off the land surface into streams and lakes or to the sea, finally finding its way back into the atmosphere through evaporation. A significant portion of the rainfall fails to be shed as run-off, but instead percolates through the topsoil and moves as underground water under a variety of conditions of flow to lower levels; some such water may return to the surface naturally as springs, swamps or be fed into surface streams, eventually meeting the same ultimate result as surface waters. This succession of events, briefly outlined here, is termed the hydrological cycle.

The significant phases of the hydrological cycle from the standpoint of water supply are run-off, as a source of surface supplies, and seepage, as a source and recharge of well supplies. It should be noted that rainfall, ultimately, is the prime source of all public water supplies.

**Characteristics of Rain Water.** Prior to the development of public supplies, rain water was directly utilized in cities by means of private cistern storage; this practice is still prevalent in certain rural areas where wells cannot be had. In the early stages of a rain, the drops wash out dust particles from the atmosphere and thus become slightly mineralized; during the later stages of a prolonged rain, however, the water approaches distilled water in purity. Since the raindrops have been formed in a gaseous atmosphere, there will be oxygen and nitrogen dissolved to saturation. Immediately when the rain contacts the earth's surface, the character of the water is profoundly changed.

**Characteristics of Surface Water.** On coming in contact

and passing over the soil, rainfall quickly acquires a variety of impurities, some tolerable and others even dangerous for human consumption. The oxygen saturation acquired during descent as rainfall is generally maintained. On striking the ground, bacterial contamination occurs, since everywhere distributed in the soil are micro-organisms, some benign, some harmless, others disease-producing or pathogenic. Soil particles become suspended, thus causing turbidity; vegetation is leached giving rise to color. Tastes and odors are imparted by vegetation, either living or dead, and by presence of wastes. Minerals are dissolved from the soil, but usually their concentration is low. Chemical characteristics of surface waters vary with season and with intensity of rainfall. The quantity available is generally unlimited or can be made adequate by proper impoundment.

From the standpoint of preparation for public utility, surface supplies are bacterially contaminated, more or less turbid, occasionally odorous, generally soft and tend to be corrosive. These faults, particularly the first, necessitate treatment according to well-established methods which will be described later in detail.

**Characteristics of Ground Water.** One of the most distinguishing features of ground water is the absence of dissolved oxygen; however, other gases, generally carbon dioxide, and occasionally hydrogen sulfide and marsh gas, are usually present in significant amounts. Due to long passage and intimate contact with soil particles, ground waters as a class are more or less highly mineralized. Particularly undesirable dissolved minerals very frequently encountered are iron, manganese, and excessive quantities of compounds causing hardness. However, this slow percolation through water-bearing sands, resembling an extensive natural filtration, is responsible for the most important and assuring characteristic of ground water, its freedom from bacteria when taken from properly protected wells. Ground water is clear; any deviation from clarity should

be cause for suspicion. All organic tastes and odors are removed in the ground-water stream by absorption on the finer sand grains. Color is met only infrequently. Ground-water quality is fairly constant over long periods of time. Unfortunately, there may be an upper limit on the available quantity, dependent on the recharge characteristics of the strata. Well water is uniform in temperature, that of water from very deep wells may be objectionably high.

From the viewpoint of suitability for public water supplies, properly protected ground-water sources should not need bacterial disinfection. There are generally required one or more corrections, such as treatment for slight acidity to control corrosion; the removal of iron and manganese to prevent turbidity on standing, stains, and other undesirable effects; and the use of a softening process to economize soap consumption, prevent heat transfer loss and control encrustation. Most of these treatment methods employ the same unit processes as used with surface supplies. Well waters after passing through a treatment plant subject to aerial contamination are always disinfected.

**U.S.P.H.S. Standards for Culinary Water.** In order to safeguard the quality of water supplied by interstate carriers, the U. S. Public Health Service has promulgated a set of standards which are based on a sanitary survey of the source, the bacteriological record of the water, and its chemical characteristics. These standards have also received intrastate adherence by sanitary officers having supervision of public water supplies. Subject to periodic revision by representative committees and professional criticism, these standards represent the best composite thought from the standpoint of public safety. For domestic use, sustained bacterial quality is the most important criterion of purity.

Limiting values have also been placed on chemical characteristics, for safety or for appeal, as listed in Table 1.

TABLE 1

U.S.P.H.S. Standards for Drinking Water, 1942 Revision

| Item                                 | Concentration, not exceeding              |
|--------------------------------------|---|
| B.coli density                       | 1 per 100 ml.                             |
| Turbidity                            | 10 p.p.m. (silica scale)                  |
| Color                                | 20 p.p.m. (cobalt scale)                  |
| Odor                                 | none                                      |
| Iron (Fe)        }                   | 0.3 p.p.m.                                |
| Manganese (Mn) }                     |   |
| Lead (Pb)                            | 0.1 p.p.m.                                |
| Fluoride (F)                         | 1.0 p.p.m.                                |
| Selenium (Se)                        | 0.05 p.p.m.                               |
| Arsenic (As)                         | 0.05 p.p.m.                               |
| Copper (Cu)                          | 3.0 p.p.m.                                |
| Zinc (Zn)                            | 15 p.p.m.                                 |
| Magnesium (Mg)                       | 125 p.p.m.                                |
| Chloride (Cl)                        | 250 p.p.m.                                |
| Sulfate (SO <sub>4</sub> )           | 250 p.p.m.                                |
| Phenolic compounds                   | 0.001 p.p.m. as phenol                    |
| Total solids                         | 500-1000 p.p.m.                           |
| Alkalinity (when lime soda softened) | Hardness + 35 p.p.m. as calcium carbonate |
| Phenolphthalein alkalinity           | 15 + 0.4 (total alkalinity)               |
| pH                                   | 10.6                                      |
| Normal carbonate alkalinity          | 120 p.p.m.                                |

Salts of barium, certain chromates, heavy metal glucosides, and other substances physiologically injurious are prohibited.

The restriction on fluorine is due to its mottling effect, if present in slightly higher concentration, on the enamel of the teeth when consumed before the formation of the permanent teeth. However, a certain minimum fluoride content, somewhere near 1 p.p.m., seems desirable for deposition of fluorine in the enamel as a protection against dental decay. Although no feasible treatment for fluorine removal has been developed on a municipal scale, effective small-size units employ contact with 200 parts of trimagnesium phosphate per part of fluoride or other large quantities of such other materials as tricalcium phosphate, hydroxyapatite, crushed bone, and, in some waters,

activated alumina. Some ground-water areas are high in fluoride.

The Federal standards also specify that treatment plants for domestic water shall be "carefully and skillfully operated and supervised by properly trained and qualified personnel." Therefore, treatment plant operators should make certain that they are properly prepared for their position of trust.

**Industrial Requirements.** Quantity and quality demands by industry upon a water supply may be quite specific. Above all, sufficient quantity must be available; for this reason, some industrials own their own wells and in certain instances a surface supply comparable to that of a city. Where unusual characteristics are demanded, supplementary treatment of a municipal supply is provided by the industry to avoid operational difficulties and low-grade products.

Hard water is objectionable for steam boilers, laundries, ice houses, dye houses, and canneries. Cooling water should be low in calcium and alkalinity to prevent deposition of calcium carbonate in heat exchanger tubes. Silica is highly objectionable in feed water to modern, high pressure boilers. Iron is detrimental in laundries and textile factories, ice houses, creameries and paper mills. Bottlers of carbonate beverages require a sparkling water of low alkalinity, without odor, and free from chlorine. Breweries prefer hard water to stimulate growth of yeast.

**Fire Protection.** Requirements for fire protection are based on quantity of water available and reliability of supply, without regard to quality. In their grading system for establishing key insurance rates, the National Board of Fire Underwriters assigns 34% of all possible 5,000 deficiency points to the water supply, whereas the fire department, the second in importance, accounts for 30%. A "first class" city or town is one receiving not more than 500 points of deficiency. In Table 2 is given the amount of water required for fire flow; this is in addition to ordinary peak-hour domestic and industrial needs.

TABLE 2  
Underwriters' Required Fire Flow

| <i>High-Value Districts</i> |  |                        |                  |  |                        |
|-----------------------------|--|------------------------|------------------|--|------------------------|
| Popu-<br>lation             | Required Fire<br>Flow for<br>Average City<br>Gallons per<br>Minute | Dura-<br>tion<br>Hours | Popu-<br>lation  | Required Fire<br>Flow for<br>Average City<br>Gallons per<br>Minute | Dura-<br>tion<br>Hours |
| 1,000                       | 1,000  | 4                      | 22,000           | 4,500  | 10                     |
| 1,500                       | 1,250  | 5                      | 28,000           | 5,000  | 10                     |
| 2,000                       | 1,500  | 6                      | 40,000           | 6,000  | 10                     |
| 3,000                       | 1,750  | 7                      | 60,000           | 7,000  | 10                     |
| 4,000                       | 2,000  | 8                      | 80,000           | 8,000  | 10                     |
| 5,000                       | 2,250  | 9                      | 100,000          | 9,000  | 10                     |
| 6,000                       | 2,500  | 10                     | 125,000          | 10,000   | 10                     |
| 10,000                      | 3,000  | 10                     | 150,000          | 11,000   | 10                     |
| 13,000                      | 3,500  | 10                     | 200,000          | 12,000   | 10                     |
| 17,000                      | 4,000  | 10                     | above<br>200,000 | 14,000<br>to<br>20,000   | 10                     |

| <i>Residential Districts</i>                         |  |
|--|--|
| Type of District                                     | Required Fire Flow<br>Gallons per Minute |
| Small, low buildings with one-third of lots built on | not less than 500                        |
| Larger and higher buildings                          | 500-1,000                                |
| High-value residences, or closely built section      | 1,500-3,000                              |
| Three-story buildings in densely built sections      | 3,000-6,000                              |

For cities larger than 270,000 population, the maximum rate of consumption, rather than fire flow provisions, generally will dictate the flow capacity of the water system. In order to concentrate flows according to the above requirements, the distribution network must be liberally sized and amply looped. Fire hydrants must be properly spaced according to type of area served. Elevated storage is advantageous. Fire insurance bureaus in various states have their own specific standards.

**Classical Epidemics Caused by Unsafe Waters.** Association of impure water with disease was suspicioned by the ancients. One of the most notable examples of appreciation of



purity was shown by the Romans who built their famed aqueducts out to springs in the hills to replace their surface supply from the polluted Tiber River. During the darkness of the Middle Ages deadly plagues befell the human race; although no scientific records exist, it is reasonable to believe that in many cases impure water was the medium through which diseases spread. Establishment of the germ theory of disease opened a new era in sanitation; now with modern bacteriology, questionable supplies can be definitely identified.

The first water-borne epidemic systematically investigated with a fair degree of circumstantial proof was the case of the Broad Street Well, London, in the year 1854. There were 616 deaths of Asiatic cholera; all the victims had drunk water from a shallow dug well, 26 feet deep, through whose disintegrated mortar lining seeped pollution from a close-by cesspool. This disaster, and many since, forcibly proved the need for protecting wells from pollution at or near the surface.

In the Laussen, Switzerland, epidemic of 1872, a polluted creek entered a nearby shallow well during high stage through fissures in a limestone strata. Pollution has been since shown experimentally to travel great distance through creviced strata, as the straining action of sand is absent. Waters from limestone strata should be disinfected when used for public supply.

It is an accepted fact now that unpoliced surface supplies, unless remotely located, always carry human sewage, and are therefore open to contamination by bacteria of intestinal diseases. In Portsmouth, Pennsylvania, in the year 1885, 1,100 cases of typhoid fever with 114 fatalities, were caused by a nurse throwing the infectious discharges of a patient on the snow where they were washed by rains into the surface supply. The practice of American cities pumping untreated surface water through their distribution systems is now but an unpleasant recollection.

Undoubtedly the most striking and convincing proof of the danger always present in raw surface supplies was furnished

by the Hamburg, Germany, epidemic of 1892. A total of 8,605 deaths occurred from 17,000 cases of Asiatic cholera caused by drinking polluted water pumped directly into the mains from the Elbe River.

Just downstream, the town of Altoona used the same source but passed the water through a slow sand filter prior to distribution. The only cholera cases reported were those of borderline families or commuters to Hamburg. This vivid contrast spurred the installation of treatment plants or adequate disinfection measures whenever dealing with surface waters. Noteworthy in this epidemic was the isolation of the causative organism for the first time.

The pumping of safe water into mains by no means guarantees delivery of safe water to the consumer, as recent outbreaks prove. During the Century of Progress Exposition at Chicago, in 1933, 932 cases and 52 deaths from amoebic dysentery resulted from such defective hotel plumbing as confused water and sewage lines and also by a drip from an overhead sewage pipe into an ice-box used to serve guests. Such an epidemic emphasizes the importance of avoiding cross-connections and back-siphonage hazards. Plumbing should be properly selected and adequately maintained.

During the year 1939, there were reported in the United States a total of 43 disease outbreaks conveyed through water. This figure averages nearly one water-borne epidemic per week. Only vigilance and attention to detail can assure a community of freedom from water-borne sickness.

During the period 1880 to 1899 the annual death rate from typhoid fever in New Orleans averaged 28 per 100,000 population. In some cities for certain years this figure exceeded 100 per 100,000. Improvements in water supply, along with better sanitation of milk and other foods, has sharply reduced the incidence of typhoid in the United States since the beginning of this century. By 1930 the typhoid death rate throughout the Registration Area dropped to 3.5 per 100,000, and in 1943 the

typhoid and paratyphoid mortality was slightly over 0.4 per 100,000. Their occurrence now is due mainly to the occasional flare-up of an epidemic permitted by violation of sanitary principles.

The main paths through which pollution has entered into potable water supplies have been :

1. Surface and underground pollution of wells and springs.
2. Seepage of surface water or sewage into gravity conduits.
3. Use of untreated surface water.
4. Inadequate control of water treatment and chlorination.
5. Leaks in submerged distribution pipes.
6. Entry of contamination into new lines while laying or into old lines during repair.
7. Flooding of waterworks.
8. Cross-connections with unsafe supplies.
9. Faulty plumbing and back-siphonage.

## SECTION 1. PROCUREMENT

### CHAPTER 2

## GROUND WATER

GROUND water, the source of approximately two-thirds of the public water supplies in the United States,<sup>1</sup> originates from that portion of rainfall which seeps through cover soil into outcropping strata. Strata that bear water in recoverable quantities are termed aquifers. There water slowly travels in the voids, forming an underground reservoir for wells and springs.

**Voids.** Voids are principally of two types: (a) Pores between adjacent particles of granular material such as sands and sand-gravel mixtures; and (b) Crevices or fissures in otherwise solid rock. Through the first type, water moves in exactly the same manner as it does through the sand filter unit of a water plant, except at a much slower rate, usually less than 20 feet per day. In this way the water undergoes a protracted process of natural filtration which frees it of any harmful pollution. Under a given condition of heads and paths, the velocity of water through uniform sands depends on the square of the grain diameter. Therefore, large size sands and gravels yield much more abundantly than do fine sands. At the other extreme in size, clays do not yield significantly at all, even though as porous as sand, because the minute grains strongly retain water. Even while solid rock is somewhat porous, it forms an extremely poor aquifer.

In the second type of voids, water flows freely, just as in any other channel, such as a sewer or a stream. Limestone and gypsum strata carry water in this manner. Pollution may be

carried great distances through such aquifers, therefore, their use for domestic water supply should be avoided or accompanied by proper disinfection.

**Water Table.** Various water bearing zones and hydrostatic pressure, or head, conditions are illustrated in Figure 1. Soil

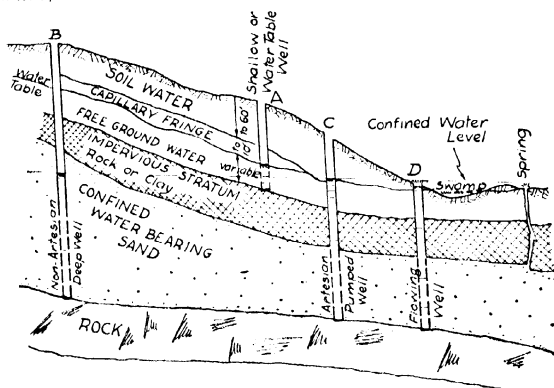


FIGURE 1

### Typical Underground Water Relations

water, loosely held in the upper layer, is utilized by plant roots, but the direction of motion is predominantly downward. Therefore, only dry wells bottom in this zone. A capillary fringe, relatively narrow in width, is generally found between the free ground water below and the soil moisture above. In this layer motion is by capillarity, as in a blotting paper, and may be either upward or downward depending on moisture conditions in the soil above. Ultimately, soil water finds a stable hydrostatic level as it seeps down into the free ground water zone. The upper level of free ground water is the water table for a given locality. This free ground water is restrained from further vertical descent by the impervious strata underneath acting as a floor. Motion of free ground water is obliquely downward according to the slope of the ground water table

and the porosity of the formation. Wells drawing from this zone, as at (A) will show a level, when idle, coinciding with the ground water table and thus shallow wells may be termed water table wells. The water table may extend occasionally above the ground surface, giving rise to a shallow spring, a spring fed stream or a swamp, according to local formations.

**Confined Water.** Far to the left of the diagram, at a higher sea level elevation, the confined water-bearing sand outcrops at the surface where local rainfall, after run-off and evaporation, gains entry. Confined tightly by top and bottom rock or clay strata, water flows under positive pressure to whatever outlets exist. Wells reaching into this confined sand will show their own characteristic level, irrespective of the local rainfall and water table. In deep wells three possible head conditions are found. At B, the standing level is below the top of the aquifer; this is a non-flowing well with a sub-normal head. C and D illustrate two types of artesian wells; both levels are above the rock ceiling over the aquifer. C is a non-flowing type, as the head is insufficient to reach the ground surface; D is a flowing well because the confined water level stands higher than the surface elevation. Should the cover rock reach close to the surface and be fissured at this point, water will escape from the confined sands as a flowing spring.

**Depth Type of Wells.** Wells are often classified descriptively according to depth. In Figure 1, A is a shallow well; B, C, and D are deep wells. Properly speaking, a shallow well may be defined as one that draws from the free ground water; it does not penetrate the first impervious stratum. Its level, therefore, is dependent upon local rainfall and seepage. Shallow wells, of 10-foot minimum depth, are safe for domestic use provided certain sanitary features are observed. Their yield is usually restricted to household needs. A deep well is defined as one that pierces the first or succeeding impervious strata; such wells furnish water supply for most municipalities. From this discussion it is evident that the description of wells as deep

or shallow has no relation to their actual depth. A former arbitrary distinction considered 100-foot depth as the dividing lines between a shallow and a deep well; such a rule is without physical foundation.

**Drawdown.** As water is drawn from a well the water level falls, due to the frictional resistance encountered by ground water while flowing into the column at the rate of withdrawal. This drop in level, as indicated in Figure 2, is termed the draw-

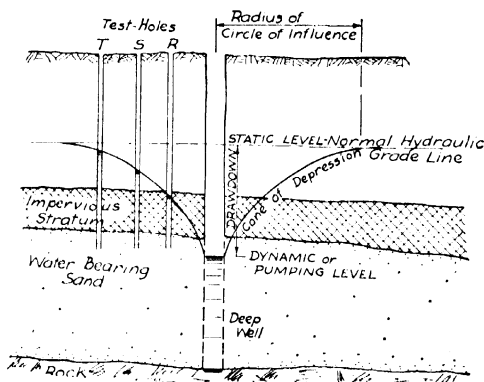


FIGURE 2

Drawdown Effects in a Pumped Well

down. In a given well, its value depends only on the rate of pumping. When the well is idle, water stands at the static level as required to balance the pressure in the aquifer.

**Measurement of Drawdown.** Drawdown may be measured in a number of ways. The most common method is based on the principle of balancing an air pressure in a tube dipping below the lowest level in the well. Some wells have such a tube permanently installed; in others, it must be inserted through the vent of piping. With the well idle, the tube is pumped up by means of a bicycle pump, until the pressure gage reaches a steady reading; air bubbles then escape from the bottom of the

tube. The well is next run at the desired rate long enough to attain a steady state, and the bicycle pump is again used to build up a steady gage reading. The difference in gage readings in pounds per square inch (psi.)  $\times 2.31$  gives the drawdown in feet.

Another method for measuring levels and drawdown consists in lowering a shielded electrode by means of a flexible insulated wire through the breather hole. When contact with the water in the well is established, a grounded electrical circuit is closed and an indicator device, such as a bell or a lamp, gives a signal. From the length of wire paid out, the depth to the water surface is given directly. By subtracting the length of wire noted while the well is idle from that needed with the well in service, the drawdown in feet is found.

A method based upon the time required for an echo to return to an instrument at the well head has been developed recently to determine water levels in closed wells.

A simple method for the determination of levels, applicable in cases where a weighted steel tape may be lowered into the well, consists in chalking the bottom portion of the tape to obtain a water mark, and noting its distance from a fixed point at the casing head.

Since the capacity of a well varies inversely with the drawdown required to furnish a given pumpage, amount of drawdown is useful as a means of comparison. *Specific capacity* is the yield in gallons per minute per foot of drawdown. In the large majority of wells, the amount of drawdown varies directly with the rate of pumpage, however drawdown-yield curves have been obtained frequently which deviate from this rule, showing either an enhanced or a reduced increase in capacity with additional drawdown. Knowing the specific capacity, or specific drawdown, the increased yield of a well can be estimated in cases where the suction and pump must be lowered due to heavy pumping or declining water levels. A change in specific drawdown, but with static level remaining practically



constant, usually indicates choking of the screen with sand or incrustation; less frequently, a damaged screen. If the static level declines with or without a change in specific draw-down, it indicates depletion of the underground reservoir. When both these quantities decrease, the sands about the well are being dewatered, and exhaustion is imminent.

**Circle of Influence.** During operation of a well not only does the water level inside the casing drop but the hydraulic grade line in the neighborhood of the well also falls. This may be demonstrated by a series of 2-inch test holes drilled at various distances from the well as at R, S, and T in Figure 2. Receding from the well, levels in each of the test holes will lie along a curve as shown; pumping of the well influences aquifer pressures to points far removed. The pattern of depressed levels in the vicinity of the well is termed the *cone of depression*, and the area over which it extends is the *circle of influence*. In the illustration shown, the bottom tip of the cone of depression cuts into the top tip of the aquifer. Such a circumstance is detrimental to forced pumping, as this portion of the sand is dewatered and friction is greatly increased by the flow being restricted through the lower portion of the sand. Normally the pumping levels will lie at elevations in the overlying rock stratum or in the shallow-level zone above. If the aquifer has not been dewatered in part, the static level will be quickly restored when pumping is stopped. If dewatering has occurred, longer time is needed for static level resumption since these drained sands must be refilled. In the case of ground table wells, this effect is very pronounced. A few localities pump clear, properly treated water from surface sources down into the strata for artificial recharge.

**Well Battery.** Recognition of the cone of depression is especially important in locating a battery of wells. Where circles of influence overlap, there results a condition termed *mutual interference*. Mutual interference may be minimized by selecting well sites at least one-quarter to one-half mile apart if

heavily drawn. Wells should be located at right angles to the flow in the aquifer. This flow is generally in the direction of the dip. Ground-water slope may be obtained also from adjacent well levels; or in case of virgin territory or strata, from test holes. Logs of these holes should be preserved, the same as well logs, for later reference.

The yield of a well is only slightly affected by its diameter, since the resistance to flow is almost completely confined to the sand strata. Doubling the size of a casing ordinarily increases the production only by about 15 to 30%.

**Determination of Ground-Water Slope.** For the actual determination of confined ground-water slope in the simplest manner, three wells or test holes should be selected to form approximately a right triangle when spotted on a map as in Figure 3 (A). Their distances from each other and static levels

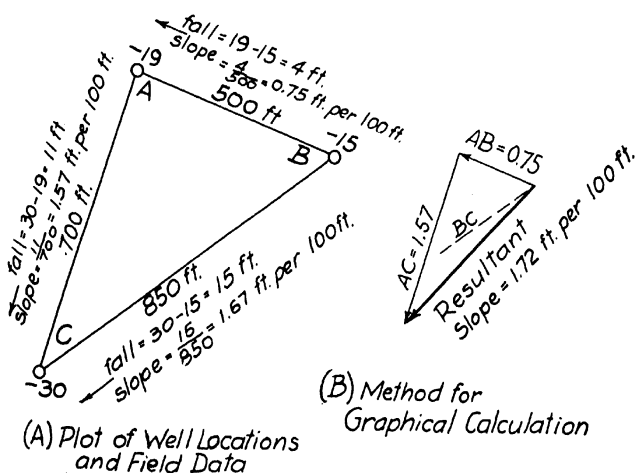


FIGURE 3

Determination of Ground Water Slope

are noted in the sketch. A common reference elevation or datum should be observed when comparing the water levels, so that irregularities on the surface are eliminated. In the drawing, wells A, B and C show static levels standing at 19, 15 and 30 feet, respectively, below a common reference point. The drop between each pair of wells is marked on the sheet, thus the fall between wells A and B is 4 feet, and the direction of flow is somewhere toward the lower elevation at A. Rate of fall, or slope in each direction is next calculated by dividing the drop by the distance between wells.

The slope of the water table is the resultant of the two slopes that meet at the right angle. Its value is found by a process termed vector addition, in which the quantities added possess direction as well as amount. In another diagram, Figure 3 (B), lay off AB parallel to the same line in the original triangle for a length of 0.75 feet; lay off AC similarly. A line drawn from the origin of AB to the end of AC is the resultant desired, and represents the slope of the water table both in direction and amount. The dotted line BC is merely to compare directions. It will be noted from the pattern of the slopes that a line running from B somewhat to the north of A will show the same static levels along its length. This line of constant level is perpendicular to the resultant as just plotted.

Wells should not be strung in a line parallel to the ground-water slope, otherwise yields are impaired. Preferably a battery should be located across the slope in order that each well is fed by its own quota of flow in the strata.

## CHAPTER 3

### WELLS

**Definitions.** A well may be regarded as a tubular opening made to extend from the earth's surface to a water bearing strata beneath for the purpose of collecting ground water. Such a passage occurring naturally is termed a *spring*. An approved type of spring construction is illustrated in Figure 4. As explained in Chapter 2, shallow wells draw water from saturated soil under the water table and their levels and yields reflect local successions of rainfall and drought. Deep wells penetrate the first impervious strata into the confined aquifers below; their behavior is independent of local conditions as they are fed at the outcrop, generally miles distant. As the aquifer beds are quite extensive, fluctuation in precipitation over the ground-water shed is smoothed out, and levels and yields of deep wells, except for mutual interference, are quite uniform. When the reservoir capacity of an aquifer is drawn on excessively to furnish supply for a battery of deep wells a permanent recession of levels will ensue; this causes lowered yields and greater pumping heads. Well water may be considered as a perennial crop only so long as the rate of withdrawal remains within the recharge capacity of the aquifer. When this recharge capacity is exceeded, the well is then worked as a mine and the aquifer is partially stripped. Obviously this condition should be avoided if ground water is to be conserved as a natural resource. Restitution of levels in a dried sand is very gradual.

**Penetration Methods.** According to the method of penetration employed to reach the water-bearing sands, wells are classified as dug, driven, or drilled. Dug wells, diameters ranging from 4 to 8 feet, tap free ground water; they may reach to depths

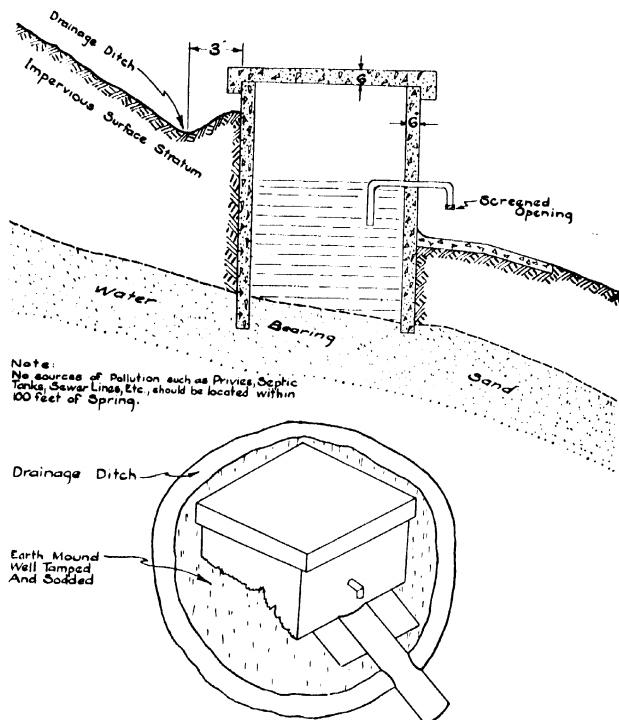


FIGURE 4

An Approved Type of Spring Construction

(Courtesy of Louisiana State Department of Health, Division of Public Health Engineering)

between 10 to 60 feet and are widely used for isolated dwellings. This type of well should be lined with a steel or concrete casing for a minimum depth of 10 feet to prevent entry of water from shallower levels. A sanitary installation for a dug well is shown in Figure 5. Driven wells consist of a hard pointed tip, fastened below a screen and casing; this assembly is driven

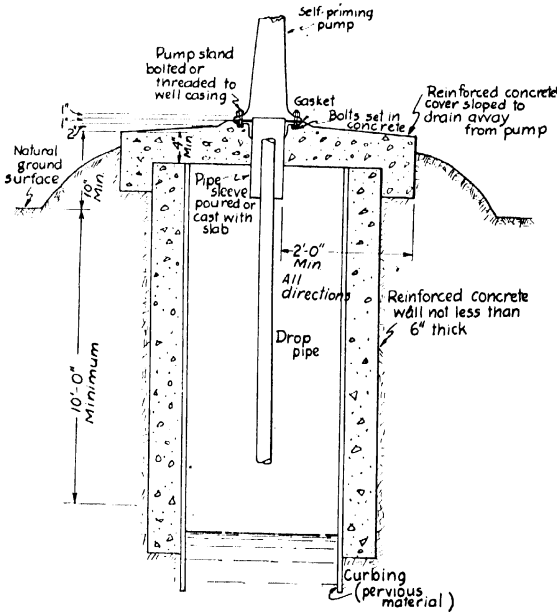


FIGURE 5

## Plan for Construction of Dug Wells

(Courtesy of Louisiana State Department of Health, Division of Public Health Engineering)

into position by hammer blows up at the surface. Casings are generally 1 to 4-inch wrought iron pipe; depths vary from 20 to 75 feet. These are also predominantly water table wells and are used mainly for homes and small institutions. A properly installed driven well is illustrated in Figure 6. In Figure 7 are shown some glaring errors, altogether too common in shallow well construction, and methods for their correction. With drilled wells, the hole is bored out with some type of heavy rotating bit; the cuttings are suspended in water or mud-laden

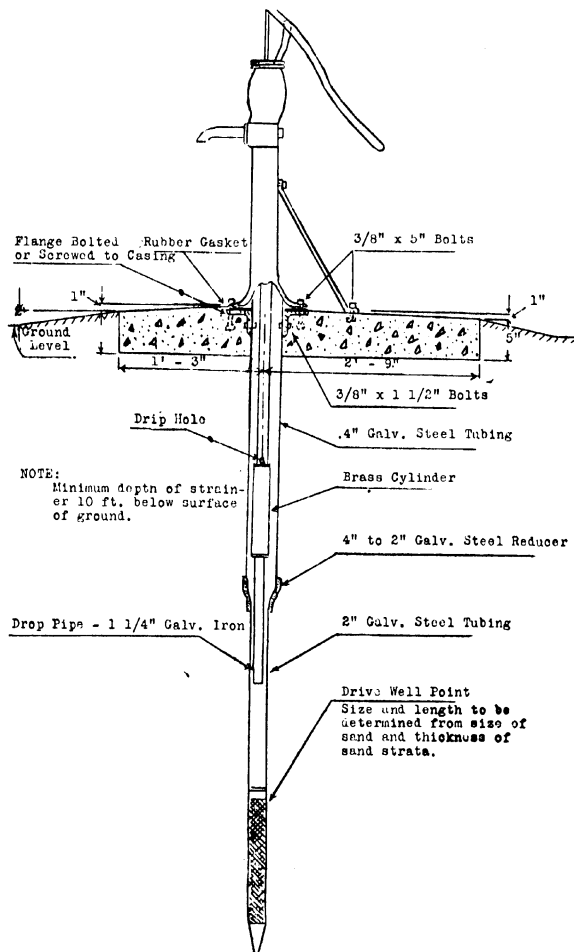


FIGURE 6

## Driven Well Details for Rural Homes

(Courtesy of Louisiana State Department of Health, Division of Public Health Engineering)

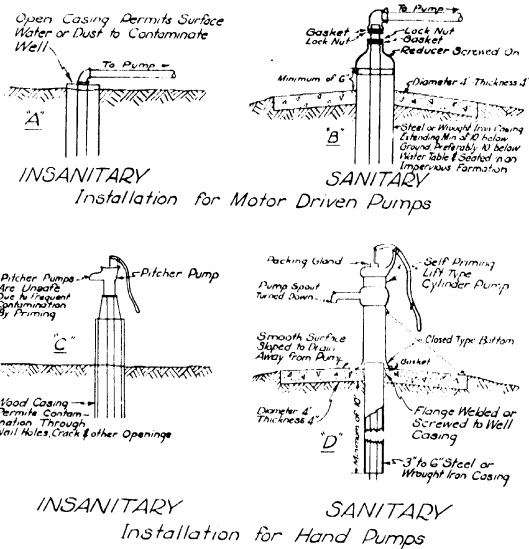


FIGURE 7

## Sanitary and Insanitary Installations for Shallow Wells

(Courtesy of Louisiana State Department of Health, Division of Public Health Engineering)

fluid from a slush pit and washed up to the surface as the cutting tool advances. The hole should bottom on a rock or tight clay stratum to give positive support to the well structure. The screen and casing are lowered into position and the latter held tightly against the side walls by pouring mud or by a cement seal. Drilled wells are usually of the deep type, where a hard formation must be penetrated or where the depth is beyond the limits of other methods of penetration. During drilling, a log should be kept and samples of material taken every 10 feet of depth for filing. Sizes range from 4 to 30 inches in diameter and depths from less than 50 to over 2,200



feet. Construction of a small bored well is shown in Figure 8. As drilled wells are used almost exclusively for municipal supplies and large industrials, their features will be discussed in more detail.

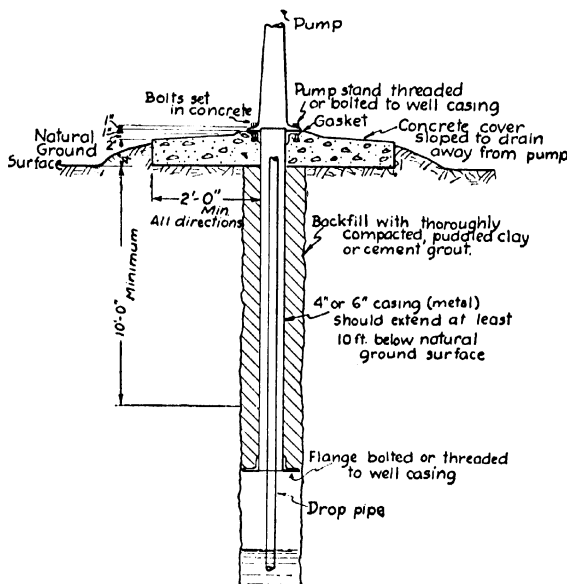


FIGURE 8

#### Plan for Construction of Bored Wells

(Courtesy of Louisiana State Department of Health, Division of Public Health Engineering)

**Structural Elements of a Deep Well.** The structural members of a typically complete deep well include a gravel wall, strainer, casing, pump bowls, drive shaft and steady bearings, drop pipe, foundation and motor.

**Gravel Wall.** Gravel walls are now provided on nearly all wells required to furnish water in sizeable quantity. In the

water-bearing sand a cavity is reamed out, 30 to 36 inches in diameter, by a toggle type folding bit, or underreamer; the screen is placed in position, then this expanded hole is filled with pea gravel. Other methods for placing a gravel wall or gravel pack are the following:

(a) An outer casing is first sunk to the full depth of the well and then pulled back after dropping in the gravel; this gravel wall will settle under development work and pumping.

(b) The outside casing is sunk to the top of the sand; then with gravel in the outer casing, the inner casing and screen are sunk by bailing into the water-bearing sand. A cone placed on the bottom of the screen spreads out the gravel pack.

(c) Gravel may be dropped into place through pilot holes drilled around the central casing.

Each gravel pack job requires detailed study to select the best method. Severe damage to pump houses and nearby buildings may result if an improperly graveled well starts to pump sand during development work or shortly afterward.

The effect of a gravel wall is to decrease the velocity of the ground water adjacent to the screen; it is in this zone that friction is the highest, therefore, by replacing the minute voids of fine sands by the larger openings between gravel, flow of water into the screen is facilitated. During use, incidental discharge of sand allows the gravel wall to drop; the space so created is filled by introducing fresh gravel at the surface. Sometimes a gravel door is provided in an extra external casing for this purpose. In some wells gravel subsidence is negligible. A gravel-wall well is illustrated in Figure 9. When gravel-wall wells were first introduced, the gravel extended up to the surface as an open magazine from which to fill spaces as they formed by sanding. This type of construction should be avoided as any seepage water, on gaining access to the open gravel descends without restraint and carries possible pollution to the pool at the strainer.

In an aquifer consisting of mixed sand and gravel, a gravel-

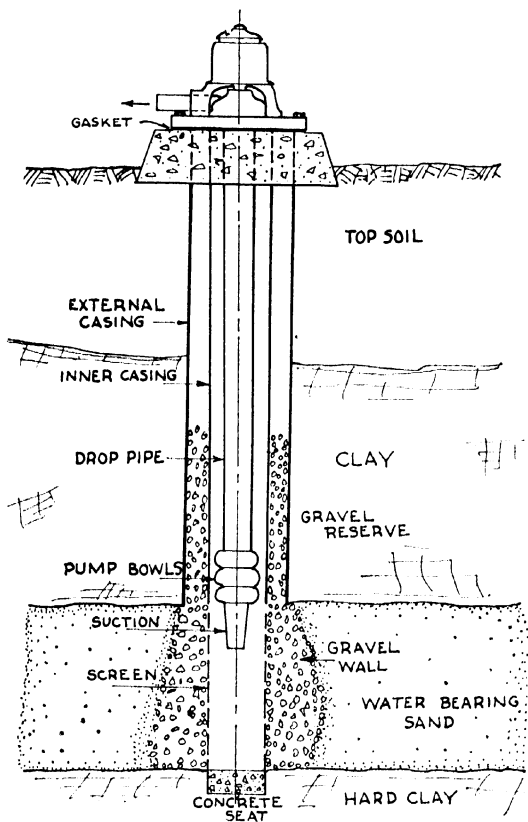


FIGURE 9

## Gravel Wall Well

wall well may be developed naturally by overpumping and surging the well during construction. Gravel walls are of greatest value when ground water is abundant, aquifers thick, and flow conditions favorable. Basically, their effect is simply

to increase the effective diameter of the strainer and to reduce the velocity of entry. Where underground flow is restrained and the drawdown surface of the cone of depression is steep, gravel walls will not increase the yield significantly.

*Ramney Collector.* Somewhat analogous in purpose, but differing radically in construction from the gravel pack, is the Ramney water collector. This device consists of a central shaft from which well points are driven radially and horizontally out into the water sands. Under certain conditions of difficult yield, as in thin aquifers, these multiple collectors gather water more effectively than does a single large strainer. Pumping is centralized in a single shaft. This device also has been planned for use as an infiltration well by laying the radial screens in the sands below a stream bed.

**Screen.** The screen acts as a strainer, holding back the sand or gravel particles from entering inside the casing into the water column. It keeps more or less intact the sand or sand-gravel zone surrounding the well, thus reducing the tendency to settlement of the whole well structure, on up to the surface. Likewise, by minimizing the passage of sand grains it reduces erosion of pump parts and extends periods between cleanings in sand traps and reservoirs. Many designs of strainers are offered commercially. Most of them consist of a fluted or slotted tube wrapped with wiring having a patented section. These sections are frequently triangular or trapezoidal, with the smallest opening to the outside; such an arrangement prevents permanent jamming of the sand grains in the openings. Small grains once entering pass on through; while large grains are positively rejected and can be forced away by backwashing. Spacing between adjacent turns of wire wrapping determines the sieve opening; these are fixed by spacer beads stamped on the wire itself. An opening is generally selected of such size that the coarser 25% of the dry sand is rejected. Screens made with unwrapped slots and perforations are also used.

Selection of the metal for the screen may be the deciding

factor in the life of a well; the choice depends upon the character of the water. When the water is corrosive, a corrosion-resistant screen obviously is indicated. However, a corrosion-resistant metal is also advisable when the water forms deposits from either iron or incrustants, as in these cases it becomes necessary at intervals to restore the yield by means of acid treatment. When conditions permit an iron or steel screen, generally a galvanized screen is used. For mild corrosion resistance, brass and bronze is selected; more drastic conditions require tverdur, monel metal or so-called 18-8 stainless steel.

By installing a smaller size screen than the diameter of the casing, through use of a packer, it is possible to pull out the screen whenever replacement is necessary. In this way a well need not be abandoned if the screen fails.

**Casing.** The casing forms a suction chamber for the pump. It also acts as a barrier to prevent access of water from shallower levels. In most wells it furnishes a pile foundation for the whole structure; when seated on a plug in underlying bedrock, the support is positive, otherwise the load of the well is carried as on a single friction piling. If there should develop leaks and sand washes, skin friction may fail and the casing part at the surface seal, thus allowing entry of pollution. When penetrating corrosive soils the metal may be shielded from external corrosion by means of cathodic protection in the case of existing wells, or by a cement jacket when setting casing in a new well.

**Cement Seal.** The casing is set tightly in the drilled hole by either a mud seal poured around the outside of the tube or cement forced from the bottom upward. Cement jackets are also used to seal off undesirable waters from higher levels when an objectionable stratum must be penetrated. Cement seals serve in addition as a protective coating around the casing, preventing damage by external corrosion. At the top of the well

the casing should be sealed in a way to ensure that no surface or shallow ground water can leak to the inside.

**Pump Bowls.** The pump bowls are suspended inside the casing at the bottom of the drop pipe through which the water is discharged to the surface. The pumps should be located below the dynamic level in order to provide positive pressure at the pump inlet. By hanging freely inside the casing the drop pipe absorbs vibrations caused in pumping and prevents their transmission to the casing. A casing subject to vibration would be liable to work the seal loose between the tube and the outside formations.

**Casinghead Seals.** At the casinghead, the drop pipe is sealed to the casing to prevent accidental entry of foreign material. An easily dismantled seal is desirable in order to minimize work when lifting the pump and delivery pipe. Several methods in use are shown in Figure 10. A simple flanged type joint is shown in Figure 10(1). The upper flange may be in the form of a split collar with sheet lead inserted between the pipe and split ring to make a fit. An all-welded joint is sometimes used, in which the drop pipe extends through a pipe cap fitting over the casing, but this arrangement entails burning and welding at every pump inspection. A popular seal consists in bolting the drop pipe to the bottom of the discharge elbow opening in the bed plate. The bed plate extends over the annular space between the drop pipe and the casing, and fits with a sheet-rubber gasket over the top of the casing. A vibration free seal is made by welding a pair of Dresser couplings to a cover plate capping the casing; the larger coupling clamps to the casing; the smaller coupling seals at the drop pipe.

**Casinghead Appurtenances.** Aside from the seal, the casinghead usually includes a motor drive, foundation or slab, delivery elbow and stuffing box for the drive shaft, vent, valves and blow off. A weatherproof-type motor and switches are used whenever the well head is not protected by a house. When

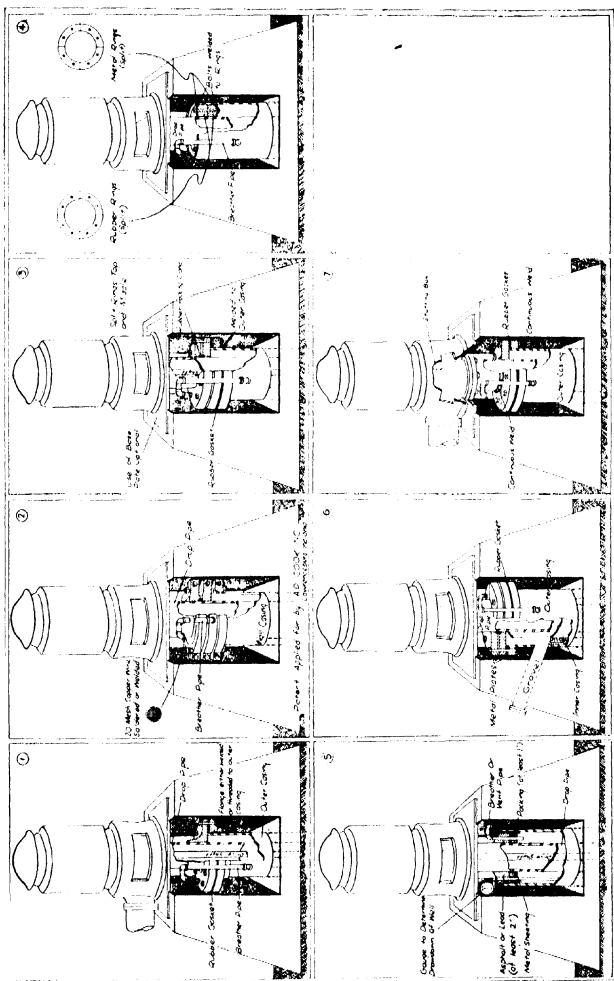


FIGURE 10  
Acceptable Types of Casing Head Construction for Drilled Water Wells  
(Courtesy of Louisiana State Department of Health, Division of Public Health Engineering)

operation or attendance at the pumping station is not continuous, an automatic switch should be installed to start and stop the motor. These switches are usually of the float-control type, actuated by the water level in the ground storage reservoir.

When a house is built to cover the casinghead, a short derrick framework is provided to pull the well as required. The foundation for the motor should be massive enough to sustain the weight of the motor and drop pipe assembly. The drive shaft enters the drop pipe through a stuffing box at the top of the delivery tube; the fitting here is usually an elbow cast as a part of the motor assembly.

**Vent.** A vent or breather pipe, as shown in Figure 10, should be provided to relieve pressure or vacuum in the casing above the water level. A vacuum tends to form whenever the pump starts; this occurs because the descending water level acts as a piston on its suction stroke. Similarly when pumping stops, the water level ascends and the air space is compressed, excess pressure being released through the vent. The vacuum-forming tendency particularly is undesirable, as contamination would be sucked in should the seals be imperfect.

**Blow Off.** Whenever the water contains easily oxidized iron in solution, a blow-off line is teed in the discharge pipe near the well. During idle periods, such as an overnight stand, some of the dissolved iron is oxidized by air from the breather pipe, causing turbid water. On starting the pump, this water is expelled through a blow off until clear; then the pump is allowed to discharge into the reservoir or distribution system. Where wells discharge an appreciable quantity of sand, a trap is sometimes placed between the well and receiving reservoir. A mechanical sand sieve with a device for self-cleansing, known as the Brassert sand strainer, is also available for desanding well water.

In the delivery line from the well is placed a check and a gate valve.

**Drawdown Gage.** Where provided, a drawdown gage is



connected by a tee to a small tube that reaches down the casing some distance below the lowest expected water level. A copper tube should be avoided near levels where it is liable to be crushed by the whip of the pump. A quarter-inch iron pipe is better suited for drawdown tubing as it is stronger and not likely to kink irregularly during insertion.

The height of water above the bottom of the tube is found by forcing air from a hand pump until the sensitive gage shows a steady reading. Knowing the depth of the end of the tubing, the water level can always be located by subtracting the water coverage indicated by the gage reading.

**Types of Pumps.** Wells are pumped by the following methods: suction, air lift, deep-well-centrifugal pumps, submersible pumps and water-jet pumps. In some areas flowing wells yield sufficient quantity without pumping. Spring water is sometimes elevated by means of a hydraulic ram.

**Suction Pumps.** Suction pumps, of the reciprocating type, are occasionally used when water levels stand closer than about 20 feet from the surface, and when casings are too small to admit normal size pump bowls. In the relatively few remaining municipal installations of this kind, the pump discharges into the elevated tank storage. With the increased mechanization of farms this type of pump has become popular for shallow wells.

**Air Lift.** The air lift was once the most widely used method of elevating water from deep wells. An air pipe, varying from one to three inches in diameter, enters the casing through a cap or tee assembly at the surface and extends for some distance below the pumping level. At its lower end it discharges air from a compressor into the suction or delivery pipe near its bottom tip. The ascending air bubbles act as a series of pistons, forcing water up through the delivery pipe to the outlet. The air is vented off from the water at the surface in a sand trap, or as in many cases, in the ground storage reservoir. In some older installations the casing serves as its own

delivery pipe; the air line, which is suspended from a bushed tee, is the only internal piping.

The depth that the air line reaches below the pumping level is termed the *submergence*; the height that water is carried above the pumping level is called the *lift*. For lifts in the neighborhood of 400 feet, greatest efficiency is obtained when the submergence is about 40% of the sum of the submergence plus lift. For lifts of only 50 feet, 65% submergence is best. In general, efficiency is low, ranging usually between 30 to 50%.

Use of air lift on new wells now is rare. Advantages offered by air lifts are simplicity of parts and operation, ease of installation, accessibility of mechanism (the compressor), possible use of a central compressor to operate a whole battery of wells, absence of submerged mechanism in the well, and adaptability to crooked holes and small diameter casings. Sandy water does not injure this device. Incidental aeration is accomplished during pumping. Since the well is under pressure, leaks at the casing head are detectable by sound; however, contamination is exceptionally rare as the system is under pressure and flow is outward. Only when the well is shut off, can contamination enter leaks, the internal pressure being relieved. Disadvantages of air lifts are high initial cost, low operating efficiency, and inability to transport water horizontally under pressure.

**Deep Well Turbines.** Deep well turbines are by far the most common type of pumping machinery presently used in this service. These are vertical pumps hung on the drop pipe below the pumping level, in bowls or stages as required to build up pressure. In the bowls are impellers and diffuser vanes. The drive generally is a long shaft directly connected to the motor at the casing head. Sometimes belted or angular gear drives are used. Steady bearings, at intervals along the length of the drive shaft, prevent whip during rotation. Modern bearings are channeled rubber blocks lubricated by the passing water. Oil-lubricated bearings are common. The well hole

must be drilled plumb; otherwise misalignment of the drive shaft will cause serious trouble. Deep-well pumps operate reliably and with high efficiency; they may deliver enormous volumes of water up to the capacity of the well. They cannot be used in very small casings; their initial cost is high; they can be reached only by pulling the well and are eroded by sandy water. Pumps are discussed at greater length in Chapter 14.

**Submersible Pumps.** Submersible pumps are vertical centrifugal pumps, the same as deep-well turbines except that the motor is close-connected below the pump unit in the well, whence the descriptive name. This compact assembly eliminates the drive shaft and its attendant alignment problems; it simplifies also the detail at the casing head, this being simply a slab through which the delivery pipe rises. A submersible pump may be used in a crooked hole.

**Water Jet Pumps.** The pumping unit is located at the surface, over or near the well. A portion of the discharge operates a jet placed below the pumping level in the well. The jetted water feeds into the pump suction and is discharged to storage, except for that portion required for ejection. Normally only two pipes are suspended down the well casing, but for wells from 2 to 6 inches diameter only a single pipe for delivery is inserted, the annular space next to the casing carrying the recirculated jet water. Lifts range from 15 to 120 feet and capacities from 35 to 750 gallons per minute (g.p.m.). Advantages of this system are simplicity, lightness, pump accessibility, assurance against lubricating-oil leakage into the well, and ability to handle gritty water. Efficiency is quite low.

**Reciprocating Pumps.** This class of pumps resembles the manually operated submerged pump cylinders used in shallow wells. A piston containing a discharge valve is worked inside a cylinder at whose base is the inlet valve. Power is applied at the surface through a sucker rod. By using hollow rods and cylinders in tandem, this pump may be made double or triple act-

ing. Only a few plunger-type pumps remain in use, having been superseded by the more popular deep-well turbine.

**Hydropneumatic Systems.** These systems are popular for large dwellings and camps; they are relatively inexpensive and are suitable for the very small community. Water is charged into a pressure tank by a pump from the well or from the ground storage reservoir. Air pressure from a compressor is applied above the water space in the tank and forces the water through the distribution system. A bellows switch operates the pump to maintain the water level between desired limits; by similar control the compressor introduces air as needed to compensate for loss by solution in the water.

**Artesian Wells.** Flowing wells are mentioned only for the sake of completeness; no pump is required unless the draught is so heavy that the dynamic level is depressed below that required for desired delivery. Flowing wells are allowed to discharge continuously into a ground storage reservoir, the excess draining off through a screened overflow line. A few small systems are known to supply consumer services directly with artesian pressure.

**Hydraulic Rams.** These are automatic lifting devices occasionally used on small supplies from springs or flowing wells with low head. This device operates by a water hammer effect utilized to force a small fraction of the available water to a higher level. They require no outside power, are dependable and inexpensive, but are noisy in operation.

**Specialty Jobs.** During well construction and repair the following specialized operations have become more or less common: cement setting, restoration of flows, acidizing, squeeze packing and shooting back.

**Cement Setting.** The cement setting around a casing is placed in position by forcing a slurry of quick setting cement up from the bottom of the tubing. Two methods are used. In the first, a packer, inserted near the bottom of the casing, is connected to a grout pump. In the second, the packer is fitted

at the top of the casing and a volume of grout, calculated to fill the annular space between the casing and the drill hole walls, is run in; this is followed by mud under pressure until the seal appears outside at ground elevation. After the cement hardens, the mud is easily removed and the cement plug at the bottom is drilled through. Such a cement seal prevents entry of shallow water, seals off undesirable upper strata preparatory to drilling lower, and protects the casing from corrosion.

**Screen and Strata Cleaning.** Except where the water level has been permanently lowered, slumping off in yield can be corrected usually by some type of cleansing action. Methods employed in attempts to restore yields include: overpumping, backwashing, dynamiting, adding dry ice, and acid treating.

Overpumping and backwashing are simple mechanical methods, intended to free a clogged screen from material that can be flushed through or forced backward. Sometimes a turbine-pumped well may be cleaned by the stirring effect from a compressed-air pipe. Dynamiting is accomplished by firing one-quarter inch sticks electrically in a bottle, every three feet advancing toward the strainer. The blast sometimes jars obstructions from the screen openings. Dry ice functions by a backwash action; this is the easiest corrective to apply. Dry ice is introduced through the casing seal which is then closed. Gasification forces water back into the strata, followed by bubbles of carbon dioxide. A pressure relief set to blow at 150 psi. should be placed on the vent pipe.

When acid-cleaning, the eduction pipe and pump bowls are removed from the well to prevent damage. Acid is introduced through a hose line extending down to the strainer level; the hose line is then removed, at the same time flushing the interior surface of the casing. Inhibited hydrochloric acid is employed; the inhibitor acts as a protective agent greatly reducing the corrosivity of the acid on exposed metal. However, precipitated iron oxides and crusts formed by scale are readily soluble, leaving the screen openings clear. Acid may be purchased with

inhibitor already added; or an inhibitor, usually a coal tar derivative, may be added to commercial muriatic acid on the job. Inhibitors that contain arsenic should be positively avoided. By adding 3% of either citric acid or acetic acid, iron will be held in solution with less chance for reprecipitation on dilution. Generally 10 to 25% strength acid is contacted with the screen. Hot acid solution acts faster and more completely on deposits than does cold acid. After standing from 2 to 8 hours, the acid is removed by resetting the pump and drop pipe, and pumping until the original alkalinity of the water is reached. By inserting packing discs in the screen, acid can be pumped under pressure through short sections and circulated back through higher sections, thus providing positive contact and cleaning.

Strong chlorine solutions are very satisfactory for cleaning deposits caused by iron bacteria. Lactic acid is successfully used in oil wells to remove iron deposits from casings.

**Casing Jobs.** Leaky casings are sometimes repaired by a squeeze packing procedure. A packer, inserted at the top of the casing is forced downward by a cement pump; it descends the tubing so long as pressure is retained. Once past the leak, a reduction in pressure is noted. At this stage a second packer is placed at the top of the casing and it, too, is forced down, but by a mud pump. In this way the cement charge squeezes out through the leak until the second packer reaches the first. Cement plugs the leak and extends some distance outward into channels in the upper strata.

Shooting back is employed to obtain water from shallower levels, supplementing the amount through the strainer. A gun or hydraulic perforator pierces the casing with the desired pattern of holes.

Other specialty services are sometimes used. When prospecting in new areas, an electrical earth resistivity survey is made to locate favorable sites directly from data obtained at the surface; this study precedes the sinking of test holes. Electric logging is suited to correlation of aquifers and the dis-

solved mineral content in the water; a systematic survey by this procedure enables the location of the best quality of water in a given area. By means of an electrical survey of the drill hole, it is possible to locate exactly the limits of the water bearing formation and from these data set the screen accurately in place; this possibility is important in the case of relatively thin aquifers or fine sands. Drill stem testing is useful to obtain rate of flow at various levels and to collect corresponding samples. Hole surveying methods are employed to check alignment. Collapsed casing can be ascertained by means of an impression gage, or by a bottom hole camera with an electric light at a lower level to photograph the silhouette pattern of the passage.

## SANITARY FEATURES

Since pollution may gain access to an imperfectly protected well supply and endanger the health of consumers, it is important that sanitary safeguards be recognized. Protective measures, many of them applicable to shallow wells also, include the following items: (1) consideration of the strata, (2) location of the well, (3) drilling precautions, (4) proper sealing and (5) adequate surface protection.

Strata selection presents a problem in sections underlaid with cavernous limestone or coarse gravel beds. Here chlorination is desirable. Generally, aquifers are sandy and act as a filter layer. If overlaid with an impervious or protective ceiling strata, such as rock, stiff clay or very fine sand, the ground water is not subject to contamination from seepage locally.

**Location.** The well site should be on high ground; if possible, above the highest known flood level in the locality. Surface drainage should flow away from the casinghead. The well head should not be located in a pump pit below ground level. Proximity to sources of pollution should be avoided. Sewer lines should be at least 50 feet away horizontally; a distance of 30

feet is allowable if extra heavy cast iron sewers having leaded joints are provided. Privies, barnyards, ponds, lagoons and manure piles should be at least 50 feet, preferably greater distances, away. In locating a well on a hillside, all sewers, cesspools, privies and pollution from above and otherwise within 300 feet should be avoided, if possible. No unfilled excavation is permitted within 10 feet from a well. All abandoned wells and test holes in the locality should be sealed with heavy clay or cement, preferably the latter.

**Drilling Precautions.** During drilling operations, precautions to be observed include provision of a sanitary toilet for the crew; chlorination of all material entering the well, such as mud, gravel, and casing; cementing off all strata likely to cause contamination; the use of clean tools; and washing off the pump bowls and string before insertion. For chlorinating the gravel pack, one-half pound of bleaching powder (25% available chlorine strength), mixed with sufficient water to give contact, is used per cubic yard of gravel before placement. Whenever the well is pulled subsequently for inspection, cleanliness of the string should be insured. Disregard of these safeguards may lead to later confusion in tracing the source of possible contamination. A most troublesome and expensive experience results when the strata become seeded with algae.

**Casing.** A durable water tight casing should line the well preferable for a depth of 10 feet below the water table, but never less than 10 feet below the ground surface. This depth has been judged to be the minimum reliable distance for water to be freed of bacteria by passing through the soil. Standard steel tubing, wrought iron and cast iron are desirable materials for casings. Masonry casing is not considered sound, as cracks inevitably appear at the joints. Brick, vitrified tile pipe, cement-asbestos pipe, galvanized well casing or corrugated metal pipe should be surrounded by a concrete wall, at least six inches thick, for a minimum depth of 10 feet. A cement seal or heavy clay should fill the annular space between the casing and



the drill hole. An adequate length of casing stub should rise above the foundation for attachment to the pump base in some types of construction or seal to the drop pipe.

**Casinghead.** A suitable foundation should be provided at the well head, such as a concrete block for the motor drive, or a concrete slab at least four inches thick, raised four inches above the surrounding ground and extending radially not less than two feet from the casing. Its top should be sloped to drain off the water away from the casing. Only self-priming pumps are permissible. The casing and drop pipe should be sealed; the casing should be vented to prevent a vacuum being pulled when the pump is turned on, and thereby tend to draw in pollution through possible leaks and to collapse a weak casing. This vent should terminate in a return bend, screened with 16 mesh brass or bronze wire to prevent entry of insects, and placed high enough above the ground or floor level to avoid dust being sucked in by air currents.

Tightness at the casinghead is absolutely necessary or contamination will always show in the water. A grossly leaking seal will be evident by the hissing sound made when starting or stopping the pump; smaller leaks may be found by pouring water over the seals with the pump idle. On running the pump, the water will disappear into the leak; on stopping the pump, a spray of water will be blown out. This test can be made more sensitive by temporarily closing the vent opening, although this point is rarely necessary. Leaks into the well are always suspected when the chemical characteristics, such as the salt content, change during a short pumping period. Dye solutions placed in test holes or pits may be used to trace underground flow through channels to a well.

**Chlorination.** When the well installation has been completed, or after repairing, disinfection with chlorine should follow before placing the well in service. The well should first be pumped to expel any turbidity and to flush out mechanically as much pollution as possible, particularly when in the form of

suspended solids. A chloride of lime solution is then introduced through a hose below the water line and worked up and down while applying the chemical so that the whole stand of water and strainer become contacted with chlorine solution. A still more positive method of chlorination, having the advantage of reaching back a short distance into the strata, consists in introducing a strong chlorine solution through an inlet, such as the check valve top, while back-pumping the well. A quick, although faulty, method widely used consists in pouring, then flushing, a chlorine solution down the vent pipe with the pump idle; the motor is then started and stopped momentarily several times in an effort to surge the chlorine solution throughout the water column. Several hours' contact is allowed before flushing out the well. The chlorine dosage is one-half pound of bleaching powder (24% available chlorine strength) per 100 feet of well casing. The powder is first rubbed into a creamy mass with water and then diluted to any convenient volume. An oak barrel, with wooden spigot, makes a good mixing vessel. The progress of well chlorination and subsequent flushout can be followed by making the test for residual chlorine, as explained in Chapter 19.

Before turning a well into the system, even though chlorinated, samples for bacterial test should be obtained, preferably through a small cock tapped into the discharge line, and tests made by the Health Department to ensure freedom from pollution. If the samples show no signs of bacterial contamination, the water is safe for public use; if the samples indicate pollution, disinfection may have to be repeated or a search made for the source of contamination. Repeatedly contaminated well water, unless the mode of entry can be detected and eliminated, should receive continuous chlorination.

## CHAPTER 4

### SURFACE WATER

**Definition.** A surface water supply is one derived from a body of water on the earth's surface; this term distinguishes such a supply from those obtained from underground sources. Sources of surface supplies might be grouped into flowing streams, as rivers; and quiescent bodies, such as lakes or impounded supplies. When the demand for water exceeds the probable average annual stream flow, a portion of the storm drainage must be stored by damming the stream. Excess water is allowed to flow over a spillway structure.

**Pollution.** As pointed out in Chapter 1, surface waters have a group of fairly definite characteristics. Because of contact with the soil and the almost universal introduction of sewage, all surface water may be presumed to be contaminated, and therefore, to require treatment before municipal use.

However, in large, protected, impounding reservoirs having storage periods of 30 days, bacterial content may be vanishingly small; but even this protection may be nullified by seasonal over-turns or by the short-circuiting action of high winds blowing water directly from the inlet to the outlet. This bacterial reduction during storage is the closest approach in nature to "self-purification." In flowing streams, bacteria of intestinal origin remain suspended and virulent for weeks. Self-purification in a stream is a myth from the standpoint of water-borne disease transmission. Improvement in water quality by stream flow refers primarily to the disappearance of introduced organic wastes by oxidation.

The extent of treatment needed depends on the degree of

contamination and other factors. There exists a limiting bacterial load for each type of treatment, as shown by U. S. Public Health Studies, above which a safe effluent will not be reliably assured.

Where practical, the degree of pollution should be controlled by police power to enforce sanitary measures or to forbid trespassing on the water shed. This measure obviously assumes ownership of a reservoir, tributary streams and land areas; with this condition, control of the pollution in the raw water provides a desirable margin of safety above that furnished by the treatment plant. Where enforced, protective measures include: frequent sanitary inspection, fencing reservoirs, patrolling the area, placarding, reforestation, restriction of recreational use, at least in the neighborhood of intakes, garbage disposal, marking off closed water areas by floating booms, prohibiting human excreta within 200 feet of the water's edge, and prohibiting septic tank and untreated effluents and wastes to be discharged into the reservoir or streams. Except in remote mountainous watersheds complete control of pollution is practically unattainable. Many treatment plants draw water from large rivers where pollution is an interstate act. At intakes located in manufacturing areas, entry of industrial wastes may depend on direction of currents as influenced by stage and winds. All surface waters therefore require reliable treatment to be made safe for public supply.

**Turbidity.** Contact with soil also causes surface waters to become turbid. During periods of sluggish stream motion or when impounded, the turbidity settles out from suspension. In the latter case, this sedimentation is important in limiting the useful life of the storage reservoir. An average silting rate, sometimes stated, is that  $2\frac{1}{2}\%$  capacity is lost per year. Where drawing water from a deep reservoir an intake structure with sluices at different levels provide for a choice of water. In rivers with turbulent flow, this device is ineffective.

**Tastes.** Contact with vegetation imparts color and taste to

the water. Growth of algae, particularly in shallow lakes and reservoirs, aggravates the taste and odor problem. Trade waste is another important source of tastes. When a new reservoir is filled, earthy tastes and odors will be present for the first few years of use.

**Variable Mineral Content.** Surface waters usually are fairly soft and low in dissolved minerals, but many watersheds yield water that is quite hard. Chemical characteristics of surface water vary with the season; following rains of winter and spring, the dissolved solids are reduced by dilution; during the dry summer and autumn, the dissolved salts reach their highest concentration. Fluctuations in physical and chemical characteristics of surface water require more or less continual adjustment of chemical treatment in the plant.

**Salt Intrusion.** Supplies derived from the lower reaches of tidal streams are subject to high salt content during periods of saline intrusion. This phenomenon is caused by the encroachment of heavier sea water upstream as an unmixed brine layer over the bed of deep rivers. Salt is transferred by mixing at the plane of contact and diffusion into the layer of fresh water above. In shallow streams salt may be fairly uniformly distributed at all depths, gradually diminishing to normal at sufficient distance from the sea. Relief from this condition may require large scale improvements, and adjustments with other interests having flowage rights. Purely local benefits may be obtained by providing storage capacity to carry over the saline period or by installing the intake a sufficient distance upstream. Engineering correctives include tidal gates and regulation of low-flow discharge by stream control. The latter methods consist of controlled diversion of flow to conserve discharge and scheduled release of water from tributary or headwater reservoirs to boost the dry weather flows. At plants subject to saline intrusion, the operator should make daily or more frequent tests, when necessary, of the chloride concentration in his plant effluent and in the stream itself. Samples taken at a

definite time or at a critical tide point, such as high water slack tide, are more significant than those taken haphazardly.

**The Hydrograph.** At a definite hour each day a reading should be made of the water level in the stream or reservoir. This is simply done by noting the elevation on a staff gage, preferably one whose zero mark has previously been set against mean sea level. In tidal streams the stages vary continuously according to the tidal type of the locality; on the Gulf Coast this pattern is one high and one low tide a day. Gages in such cases should be read at least twice daily. When elevations are plotted in daily sequence on graph paper, the resulting curve is termed a *hydrograph*. This hydrograph may be made to serve as a background for study of many natural occurrences affecting operation of the water plant. Characteristics whose study is aided by the hydrograph include rate of discharge, turbidity, various chemical characteristics and saline intrusion in the case of supplies near the mouth of a river. An operator of a surface supply should regard the hydrograph as an integral part of his daily log.

**Algae Control.** Algae are a low form of plant life, whose position in the scale of development lies between bacteria and the higher types. Most of them contain green coloring matter and, therefore, can grow abundantly when provided with air and sunshine. Clear, quiescent streams furnish a favorable habitat; in them algae multiply rapidly, releasing oily materials from their cells during life and unloading their contents after death. These essential oils cause tastes and odors characteristic of the species of algae involved. As heavy growth of algae follows periods of strong sunlight, sluggish dry-weather flows of clear water in summer and autumn are ideal for propagation of algae. In a reservoir, or portion of a lake, their growth is discouraged by application of copper sulfate. Methods of application include dragging sacks of this material from the stern of a boat, feeding solution from a barrel, and dusting finely-ground powder directly on the water surface. Immedi-

ately after killing algae, taste intensity increases due to the release of the oil globules from their cell contents. Concurrent taste reduction treatments are in order at the treatment plant. Further consideration of this problem is given in Chapter 13.

## SECTION 2. METHODS OF TREATMENT

### CHAPTER 5

#### GENERAL AIMS AND METHODS OF WATER TREATMENT. STORAGE

**Surface Supplies.** Rarely is a water completely satisfactory for public use without some degree of corrective treatment. Surface waters may be regarded with certainty as being polluted, thus requiring at least disinfection and generally requiring coagulation and filtration. Except for supplies provided with protracted storage, surface supplies as a class also require turbidity removal and frequently taste and odor control.

**Ground-Water Supplies.** Theoretically, well waters should be free from bacteria, thus needing no corrective disinfection. Safe well water can be assured only by proper attention to sanitary safeguards as outlined in Chapter 3. Occasionally, normally dependable wells will give bacterial tests indicative of pollution and the offending source must be found. Usually the trouble will be located at a broken seal between the casing and drop pipe or some other defect at or near the casinghead. If it is impossible to locate the defect and the well continues to give poor bacterial tests, the water supply should be continuously chlorinated. Chemically, a typical ground-water fault is the frequent occurrence of dissolved iron salts. A few well supplies, containing over 1.5 p.p.m. fluorine should be abandoned for other sources when practical, as defluorization is very expensive.



**Over-All Aims of Treatment.** Aside from the presence of turbidity and organic tastes and odors in surface supplies, and frequent iron in well waters, both ground-water and surface-water types may require treatment for removal of excessive hardness and for corrosion control. Over-all treatment purposes are summarized according to source of supply in Table 3.

TABLE 3

## Types of Treatment Usually Needed

|            | Ground Supply  | Surface Supply  |
|------------|--|---|
| Infrequent | { Disinfection<br>Manganese removal  | { Color removal<br>Iron and manganese removal   |
| Common     | { Removal of gaseous odors<br>Iron removal<br>Softening<br>Corrosion control | { Disinfection<br>Turbidity removal<br>Taste and odor control<br>Softening<br>Corrosion control |

**Methods.** Several of the above objectionable characteristics can be remedied by a single type of operation. Therefore, it is helpful in discussing basic fundamentals to consider present means of treatment as unit processes. The processes now utilized in treating water supplies are:

Storage  
Aeration  
Coagulation  
Sedimentation  
Filtration  
Exchange Processes  
Adsorption  
Disinfection

The applications of these processes will be outlined in the chapters immediately following. Because of its significance to public health, disinfection when required, is mandatory. When the other corrective processes are desirable from the standpoint

of appeal or economics, their employment is a matter of local appreciation and decision. Restrictions of the U. S. Public Health Service prescribe certain limits when the supply is to be used by interstate carriers. Indirectly, any undesirable physical or chemical characteristic is a dangerous defect because consumers are encouraged to search for private sources of supply which may be unsafe.

## STORAGE

Apart from the function of procuring volume, extended storage in reservoirs or lakes may be considered as a method of treatment because the following beneficial changes occur in the water:

1. Reduction of suspended solids by sedimentation.
2. Removal of most bacteria by sedimentation and by biological conflicts.
3. Oxidation or precipitation of organic pollution.
4. Provision for more uniformity in the character of raw water.

Disadvantages of open storage may be listed as:

1. New reservoirs impart earthy tastes and may cause coloration of the water.
2. Algae control is constantly needed.
3. Taste and odor control may be necessary at the plant.
4. Spring and fall temperature changes cause a deep reservoir to overturn as a mass; stagnant bottom water, deficient in oxygen, is brought to the surface.
5. Unless provided naturally by a nearby lake, impounding reservoir construction cost may outweigh its advantages.

Considered from the standpoint of treatment advantages alone, a reservoir does not match the performance of a treatment plant. This latter is usually more economical, selective, and reliable.

When subject to inflow of turbid water from tributaries,

some plan should be developed to discharge as much of the sediment from the reservoir as possible in order to avoid loss of capacity through silting. A drop wall near the outlets provides a means to flow silt-laden waters through deep reservoirs without disturbing the clearer waters at the surface. Electrically charged screens have been used with some success to repel fish from entering the intake.

## CHAPTER 6

# AERATION

**Objects.** Aeration, as the term implies, is the intimate contact of the water with the atmosphere. Functions performed by this act may be classified as follows:

1. Degassing. This is purely a mechanical process by which undesirable gases are swept out into the contacting air. Only gases and highly volatile liquids whose boiling points are below 25 to 50°C. can be expelled by aeration. Thus, organic oils and odors, such as those caused by algae, are only slightly affected. Certain trade wastes odors, however, have been greatly reduced by spraying under pressures ranging from 50 to 110 psi. into a fine mist. Gases removable by this means are listed in the following.

*Carbon Dioxide*, almost universally present in ground waters, is removable down to a low limit. Presence of carbon dioxide increases the acidity of a water, tends to retain iron in solution, generally causes the water to be corrosive, and consumes alkali in a chemical treatment plant. When carbon dioxide is less than 10 p.p.m., its reduction is more economically accomplished by lime than by aeration; the slight increase in hardness is usually advantageous in soft waters. Carbon dioxide is also reduced by limestone contact beds, but at the expense of increased hardness.

*Hydrogen Sulfide*, the gas responsible for the rotten-egg-like odor found in well water of certain localities is removed by aeration through two separate effects; the mechanical sweeping out action accounts for most of the removal, whereas chemical oxidation plays only a minor role. This gas can also be

destroyed by chlorination, if the content is not so high as to cause turbidity from precipitated sulfur.

*Methane*, or natural gas (marsh gas) in a water supply causes a garlic-like taste and constitutes an explosion hazard when its escape into air in confined spaces permits concentration of 5 to 15% to be reached. At least four water works explosions, attributable to the ignition of released methane, are on record.

*Excess Chlorine*, may be reduced by aeration when objectionable to taste; more frequently, however, excess chlorine is allowed to become dissipated during retention or destroyed by chemical means.

*Ozone*, in excess, is very readily removable by aeration.

2. Oxidation. Oxygen from the atmosphere combines with easily oxidizable substances present in the water. Iron present as ferrous bicarbonate, a common form of occurrence, is oxidized to an insoluble rust which on precipitation reduces the iron content to a low figure. Manganese is likewise precipitated if the acidity of the water has been properly reduced. Oxidation of hydrogen sulfide has been mentioned before. Aerators are generally more efficient in saturating the water with oxygen than in removing carbon dioxide; this added oxygen is detrimental from the standpoint of corrosion.

3. Chemical Mixing. In some aerators use is made of the free fall to effect a uniform mixture with applied chemicals.

4. Other Actions. Other incidental actions achieved by aeration are unimportant. Only minor bacterial improvement is produced through exposure to sunlight and oxidation. Tastes caused by algae are hardly affected, although fragile forms are damaged where shock is severe; in this way propagation of algae in the plant may sometimes be discouraged. As decorative devices, some types of aerators may be made into illuminated fountains and falls.

**Types of Aerator Equipment.** Aeration equipment is quite simple, frequently the least involved device at a water plant. It is inexpensive to build, and if well selected, gives good per-

formance. Even an air lift will act with fair effectiveness as an aerator. Classification of aerator types may be made as follows:

1. *Spray Type*. This class of aerators, which distribute water as a fine spray through the air, may be subdivided into spray towers and spray nozzles. In the spray tower, water falls freely from distributor pipework which may be perforated or provided with nozzles. The fall may sometimes be broken by a layer of wire netting or boards. Spray nozzles sprinkle the water upward in fine droplets which are caught in the collecting trough underneath. Forceful impact of the jet against a solid deflector has been found to release dissolved gases more effectively than by free fall. Two types of nozzles are available: The adjustable cone type in which a central deflection plug is adjustable by a screw, thus allowing the degree of dispersion to be varied; and the floating cone type in which a weighted plate or cone rests loosely in the orifice causing a fixed loss of head for any discharge. A louvre wall enclosing the device prevents winds from blowing the spray beyond the enclosure. This device is widely used in towers or above ponds to cool recirculating water in power houses.

2. *Shelf Type*. As the name suggests, contact with air is promoted by the splashing and film flow of water during its fall through a series of trays. Generally, the shelves are arranged one below the other vertically. The slat-shelf aerator consists of open-work slats, laid in alternate directions in each successive shelf. The cascade aerator is a nest of concentric pans, built with expanding radius, one below the other, around a central riser. Water overflows the lip of a pan to the one below; aeration occurs mainly in the splash zone. In addition to lip overflow, some cascade aerators have perforations in each shelf so that greater capacity is obtained. The coke-tray aerator contains fist-sized coke in a tier of perforated trays, each about six inches deep. Good splash action and film exposure is obtained. The percolation of water through the coke bed is not an instantaneous matter, hence a desirable time element of contact

is allowed by this means. The number of trays usually varies from three to six. Considering its efficiency and low cost of construction, the coke tray is a justly popular device. Where iron removal is required, the coke tray provides a surface to hold the precipitated iron oxide, thus catalyzing or accelerating iron reduction. The rifle-type aerator is a flight of stairs over which the water descends in turbulent fashion; at each step there is a jump and churning which entrains air.

3. *Diffused Air Type.* In distinction from the previously described methods, the diffused air principle passes air through the water rather than spraying water through air. Here the problem of obtaining proper subdivision of the ascending air bubbles in a stream of water is met by distributing compressed air through porous plates or tubes. Materials used as porous media are carborundum and alundum. This process is borrowed from the activated sludge treatment for sewerage.

4. *Manufactured Types.* A number of fabricated aerators are available from manufacturers. The Aeromix consists of a number of drop tubes through which the water falls, sucking in air at the same time; on discharge, at a lower level, the air is released. Chemicals may be introduced with this device for quick mixing. The Multicone consists of a tier of bowls with aspiration channels and air release troughs; during descent, water is subjected to the bubbling action of the entrained air. Forced-draft aerators are usually of the slat-shelf type enclosed in an air duct through which a blower discharges. The de-gasifier is a tall column built on this principle. These designs are used mainly where space is at a premium and high carbon dioxide concentrations must be reduced.

**Maintenance.** Aerator maintenance is mainly a matter of cleanliness. Usually placed in the open where sunlight is abundant, the wetted surfaces, catch basin, and louvres offer ideal sites for the growth of algae. Trouble from algae can be overcome permanently by building a canopy to shade the aerator. Screening the structure prevents nesting of birds under

the gable. A walled enclosure around an aerator will shield the water from dust contamination, but at the same time will slightly reduce the removal of carbon dioxide. Spray nozzles should be cleared whenever their flow gives evidence of clogging. Coke trays, especially in iron removal plants, need frequent cleaning to keep the water passages open. Hosing is effective only on accessible surfaces. Satisfactory cleaning is assured by completely removing the bed so that the interior can be reached. A rotary tumbler or rattler will quickly clean a pile of dry coke. Rust-resisting material, like copper-bearing steel is desirable for construction of the aerator. If wood is used, cypress or redwood should be selected; joints rather than nails should be employed as much as possible. Only heavily galvanized steel, brass or copper hardware will withstand the corrosive conditions.

**Controls.** As well waters are usually quite constant in characteristics, a particular aerator should give uniform performance; therefore, testing as daily routine is unnecessary. Occasional testing is advisable for the purpose of obtaining current information and to make certain that no performance is lost by clogging up. Tests of a unit are of considerable value for acceptance, appraisal, or to furnish basis for revision. The chemical test most useful in this connection is a titration for carbon dioxide content; a pH determination is also significant. Total alkalinity will not change perceptibly on aeration, except in supplies high in iron. Knowing the pH and alkalinity of a water, the carbon dioxide may be obtained from a chart. Dissolved oxygen tests usually show that saturation is approached even at the first tray drippings. Procedures for making these tests are explained in Chapter 19.



## CHAPTER 7

# COAGULATION AND SEDIMENTATION

**Types.** Sedimentation basins may be classified broadly into two types: plain sedimentation tanks and coagulating reservoirs. Plain sedimentation, presedimentation or degritting reservoirs consist simply of a basin of sufficient cross section and length to provide low velocity and retention time needed for preliminary removal of sand and coarser silt in advance of regular plant treatment. Concurrent bacterial reduction is also noted in these basins. Except under special conditions, such as an excessive burden of coarse sediment or preparing water for long transit through pipelines, the economy of presedimentation as a part of plant treatment is doubtful. Coagulating reservoirs are essentially sedimentation basins in which particles settle out following treatment with coagulating chemicals.

**Mode of Sedimentation.** Sedimentation is a process in which coarse particles are allowed to settle out from suspension in water as it passes quietly, at a low velocity, through a reservoir. While in turbulent motion, water can carry large sand grains in suspension, but when the flow is reduced, particles progressively smaller in size, will fall to the bottom. The tendency of a given particle to settle through quiescent water depends upon its size, shape, specific gravity, and the temperature of the water. The specific gravity of soil particles will vary but little from an average of 2.65; however, variations in specific gravity are important with chemically coagulated materials. Temperature is important because of its effect on the viscosity, or fluidity, of the water. Cold water, being more viscous than when at ordinary temperatures, will present more

resistance to the downward motion of particles and thus impede their settling. In plain presedimentation tanks intended for the removal of coarse turbidity, without coagulation, the material to be settled is mainly soil particles in the size range embraced by the terms sand and silt. Roughly, sand grains will settle proportionally to their diameter. Spherical shapes settle faster than flat angular bodies. Very finely dispersed particles tend to remain in suspension almost indefinitely due to two effects. Obviously their small size is one factor; but probably more important is the fact that minute particles, termed colloids, carry an electric charge on their surface. Negatively charged clay particles in suspension will repel the approach of other like particles and, therefore, the mass will tend to remain separate or dispersed throughout the water.

**Definition of Coagulation.** Coagulation is the process of causing the finely divided materials suspended in water to cluster together. This is necessary in preparing water for filtration. Otherwise nearly all impurities would pass through the sand bed.

**Mode of Coagulation.** Two separate effects are in action. The coagulant in solution furnishes electrical charges; these are of opposite sign and thus will neutralize the charges on the suspended matter, permitting them to come together. In water, the coagulant undergoes a chemical change to form a gelatinous precipitate. In this, the suspended particles are enmeshed; the aggregate is a fairly large feathery mass, called *floc*, of sufficient size and weight to settle out. During sedimentation the floc drags down turbidity and bacteria; this bacterial removal is of utmost importance, as highly polluted waters can be safely treated only in a plant employing coagulation. When the floc is very bulky, reduction of dissolved substances such as odor, silica, and fluorides is noted; this is done by an associated effect termed adsorption. The role of flocculation in a water plant may be visualized by the comparison between a fog and a snowstorm. Coagulants also catalyze or accelerate the progress

of softening reactions and many of them, by their acid character, tend to reduce after-precipitation.

Chemicals used as coagulants include aluminum sulfate, copperas (iron sulfate), ferric sulfate, ferric chloride, chlorinated copperas, lime, and sodium aluminate. Except in the case of lime, all these materials, in water of controlled alkalinity, produce a hydrated metal oxide floc. Lime acts incidentally as a coagulant by raising the pH of the water, thus expelling much of the soil colloids from water. The resulting formation of calcium carbonate crystals around cores of soil particles also aids their removal. High lime dosage in the caustic alkalinity range, as in full softening, will precipitate the magnesium present as magnesium hydroxide; this product has excellent coagulating properties. Lime is detrimental when color is to be removed from water. Bentonite, a volcanic clay, by virtue of its swelling properties when wetted, has coagulating action in hard waters. Sodium silicate, activated in a special manner by incomplete acidification or other methods, is very effective in aiding the coagulating action of alum or copperas. Activated carbon mixed with alum promotes the coagulating action somewhat. Superchlorination facilitates coagulation by oxidizing organic compounds which act as protective colloids.

**The Jar Test.** Each coagulant responds specifically to the conditions of use. Since economy of material and efficiency of performance depend upon understanding the factors controlling the behavior of a coagulant, every plant operator employing coagulation should study the action of various coagulants on his own particular water. Supplies derived from flowing streams require very frequent adjustment of dosage; a jar test will furnish a helpful guide. On a small scale, the jar test will provide directive information useful in making plant adjustments or in comparing competitive coagulants. The apparatus is a row of jars, gallon size is preferable, stirred mechanically by paddles. Stirring velocity should be adjustable. The coagulant solution is added quickly while the jar

is stirred as violently as possible; the stirring is immediately tapered down as soon as mixing is assured, so as to promote floc formation and prevent breaking the clusters. Final stirring should be a slow, easy rotation just sufficient to keep the floc in suspension and roll it together into larger masses. Controlled growth of floc is termed *conditioning*. The mixing and floc-building action in a laboratory test will generally surpass that observed in the plant, however the results may be interpreted correspondingly. Another stirring procedure, seeking to imitate plant conditions, consists in agitating the treated water sample at such a stirring speed that when the stirring time allowed is equal to that in the plant, the laboratory result will be similar. Either method of stirring will yield valuable information. More detailed directions for jar test dosage calculations are given in Chapter 19.

**Quick Mixing.** The acts of quick mixing and floc conditioning are vital in efficient plant operation. Addition of a coagulant should never be in steps, as the results are unmistakably inferior. When two separate coagulants are used, each should be followed by a period of conditioning and settling. Coagulant solutions should be prepared in concentrations and batch sizes sufficient to last a convenient length of time, generally a day, so that the operator may be spared from too much attention to this detail. Unless an effective quick mix is provided, a liberal amount of dilution water should be added to the coagulant solution immediately before mixing with the water undergoing treatment. Quick mixing may be provided by introducing the coagulant at such points as at a low lift pump suction, before an agitator or paddle in a mechanical mixing chamber, at a hydraulic jump, in an eddy at a corner in a flume, or just before passage through some such obstruction as a gate or orifice. When the plant as originally built does not provide for a quick mix, this feature may be supplied, in a small basin, by means of a portable motor-driven propeller clamped to the side of the tank. The coagulant solution should

hit the water and disperse immediately; it should not streak off as a colored or marked band. The time required for mixing is that needed to distribute uniformly the added chemical through the water; as mentioned before, this should ideally be in a flash. Where existing conditions necessitate a measurable time interval for a mix, no greater mixing period than required should be used. To do so would be to interfere with floc formation, a step requiring more gentle motion. Quick mixing is not necessary with insoluble coagulants, such as lime. Lime should not ordinarily be added to a pump suction because of deposits that form on the pump parts.

**Floc Conditioning.** When floc first forms, it is minute in size; if the dosage has been adequate and no disturbing effects interfere, the floc aggregate grows by gathering other floc particles. Efficient operation of a coagulating plant depends on how skillfully an operator can induce the association of floc masses into large units. Fortunately most coagulants, when dosed sufficiently, will produce a floc that will settle, but by paying attention to floc conditioning features, the coagulant dosage may be radically reduced. Given a certain required minimum of coagulant present, it may be stated that proper floc conditioning is more productive of efficient operation than is addition of large excesses of chemicals. Thus floc conditioning may be considered as the most important single step in coagulation. This fact may be strikingly demonstrated in a jar test consisting of two sample treatments, both with the same chemical dosage, one with prolonged high mixing velocity, while the other has tapered stirring, finally terminating in very slow motion. As a result, the latter sample will be unmistakably superior. Certain types of flocculating motion will emphasize this contrast more than others.

**Flocculating Devices.** In the plant, flocculation may be provided by a number of devices; in some the motive is simply a gentle prolongation of the mixing act; in others special equipment is installed for the purpose. In baffled flow mixing basins, an effort at flocculation control is made by building

succeeding channels of increasing cross section, thus reducing the velocity of the water and consequently its turbulence. A fundamental disadvantage of this scheme is its lack of flexibility; if the pumpage is variable, a basin of this type cannot keep conditioning performance constant. Tapered stirring in partitioned mechanical mixing basins is an effective method. The conditioning effect here is obtained by slowing the speed of stirring from one section to the next, by reducing the blading on the agitators progressively, and by increasing the retention time in each stirring section. Flocculators may be placed in the entrance end of coagulating basins. These devices consist of slowly revolving horizontal paddles having diameters nearly equal to the water depth; usually the paddles are installed four units across, with successive paddles turning in opposite directions so that the water is gently rolled. Such motion is conducive to floc growth. Several types of floc conditioning equipment are available that use gentle reciprocating motion of specially shaped arms or plates. Structural features of a basin may also provide rudimentary floc conditioning. A basin provided with a sill placed in proper relation to the inlet will deflect the entering water in such a way as to cause gentle eddying. Some plants, without intentionally providing for floc control, achieve a certain degree of flocculation by virtue of the twists and turns the water must make in passing from the mixing chamber to the coagulating reservoirs. This accidental conditioning may be overstepped during periods of high pumpage. Generally sharp turns, small valve ports and high velocity in the transfer conduit will break previously formed floc and even present a serious difficulty to plant control.

An open flume leading from the mixing basin to the coagulating reservoirs is preferable to a pipeline in a lime softening plant. This avoids incrustation in inaccessible passages, which eventually may become the bottleneck in plant capacity.

**Coagulants for Color Removal.** Coagulants are employed for three main purposes; to reduce turbidity, bacteria and color. Usually the bacterial reduction is accomplished concurrently

with either of the other purposes and is not generally thought of when choosing a coagulant. For the reduction of color, alum is generally superior to the iron salts. For purpose of preliminary estimate color is reduced at the rate of 10 parts per million per one grain per gallon of alum; actual performance is found only by means of jar tests or observations in the plant. A low pH value ranging near 5.5 is helpful and may be necessary. When the water is high in alkalinity, economy will be effected by a preliminary addition of acid. Such water will require subsequent corrosion control. Liming the water is detrimental and may stabilize the color. If the water is to be lime softened, this step must follow removal of the color floc after the first set of coagulating reservoirs. Copperas is unavailing for color removal; with some vegetable coloring matter conditions will be aggravated. At an extremely low pH, the ferric salts may be effective in color removal, but a heavy addition of alkali is later required to restore the water to a suitable pH value.

**Coagulants for Turbidity Removal.** For the removal of turbidity, the plant operator may choose from the whole list of available coagulants. Usually many of these materials will perform satisfactorily, but an economical and optimum choice is a matter of experimental study and judgment. For this purpose, the stirring machine and jar tests are indispensable, as only by this means can various possibilities be quickly and systematically tried.

**Alum.** Flocculation by alum is due to the formation of aluminum hydroxide. At pH values below 6.5, the coagulum contains increasing percentages of basic aluminum sulfate. To form these compounds alum reacts with the bicarbonate of the water; if the alkalinity is insufficient to satisfy the acid character of the alum, alkali, usually lime, less frequently soda ash, must be added else the water becomes quite acid and actively corrosive. Theoretically, one grain per gallon of alum requires 7.7 parts per million of bicarbonate alkalinity for reaction.

Actually, however, due to side reactions, plant records show only 6 to 7 parts per million in alkalinity reduction. A residual alkalinity above 10 to 20 parts per million should be left in the water. When the natural alkalinity of the water must be supplemented by alkaline compounds, one grain per gallon of alum will require 6 parts per million of hydrated lime or 8.3 parts per million of commercial soda ash. Addition of one grain per gallon of commercial hydrated lime, in this manner, will increase the non-carbonate hardness by 0.22 parts per million; soda ash is without effect on hardness, but its chemically equivalent dose costs about four times as much as does lime. When alum reacts with natural bicarbonate or with soda ash 0.88 and 0.42 parts per million, respectively, of carbon dioxide are released in the water per part per million of the chemical involved; for every part per million of carbon dioxide that should be neutralized to maintain a pH value sufficiently high for corrosion control, there will be required in addition approximately 0.84 parts per million of hydrated lime or 2.4 parts per million of soda ash.

A limited range in effective pH values should be recognized. If the water is too acid, some of the alum remains in solution; inversely, when the water is too alkaline, alum floc tends to redissolve. Added to the undesirability of dissolved alum in the effluent and its waste in this manner, is its impaired action as a coagulant. For turbidity removal, the behavior of alum depends largely on the kind and concentration of dissolved salts in the water. In general, hard waters are more readily coagulable by any coagulant, but this peculiarity is particularly true of alum. In distilled water, alum will coagulate only in the neighborhood of pH 6.5. In the presence of sulfates, the zone of effective coagulation may be lowered to reach below pH 5.5; chlorides exert a similar but less marked effect. The presence of calcium facilitates flocculation in the alkaline range to over pH 8.5; sodium salts are less helpful. From these facts, it may be noted that in a hard water alum will precipitate with



fairly uniform effectiveness through a wide pH range; or in other words, its action under these conditions is independent of the pH value. However, as the content of dissolved salts decreases, pH control in alum coagulation becomes increasingly important so that this process must then be performed at its optimum pH point.

**Copperas.** Copperas, or ferrous sulfate, has many of the characteristics of alum, with some notable advantages. Copperas may react with the natural alkalinity in the water to form a hydrous iron oxide, but generally lime is used in advance for its softening effect and pH elevation. Lime requirements for direct reaction with various coagulants are given in Tables 5 and 6. Dissolved oxygen is required to oxide the precipitate to ferric hydroxide, otherwise its coagulating power is seriously diminished. Surface waters contain sufficient oxygen ordinarily to accomplish this result, but well waters require preliminary aeration if ferric hydroxide is to form. In many cases the combination of lime and copperas is more economical for coagulation than is the simple coagulant alum. To this must be also credited the softening action of the lime and the fact that the plant effluent is generally not corrosive. No pH control is necessary with copperas, provided this value is above about 6.5. At high pH values, iron floc does not redissolve as does alum floc. On the contrary, the higher the pH is carried, the sharper will be the floc formation. Control of lime treatment is needed only to regulate alkalinity. Iron floc is smaller and heavier than that formed by alum. Since copperas is a by-product, recovered from waste pickling liquors at iron and steel mills, it can be purchased at a price advantage over other coagulants.

**Sodium Silicate.** In alum or copperas plants operating near capacity or subject to periods of faulty coagulation or overload, the pre-dosing of the water with partially acidified sodium silicate promotes the formation of a tough heavy floc. This floc improvement is valuable in those plants whose design causes

damage to the floc during its transfer from the mixing chamber to the coagulating basins. The sodium silicate is best prepared from a material having a high silica to soda ratio; the chemical is diluted to near 5% solids concentration and treated with sulfuric acid to allow a residual alkalinity of about 1,150 p.p.m. At least five minutes' ageing is needed before application of this solution to the water. Careful manipulation is required in preparing this mixture; otherwise efforts are wasted and may even be detrimental. Another method of using sodium silicate consists of mingling a solution with alum in the feed line en route to the mixing basin. In lime-treated water activated silica may be used without any other coagulant. Other types of activated silica sols are being developed; one, known as Ensol A, is prepared by neutralizing a sodium silicate solution with ammonium sulfate, otherwise used in connection with the ammonia-chlorine treatment.

**Ferric Salts.** Ferric salts used as coagulents include ferric sulfate, ferric chloride and chlorinated copperas. The last is made directly at the plant by introducing sufficient chlorine into a copperas solution before dosing the water, or by chlorinating right at the point of entry of the copperas into the water. Ferric salts do not require the presence of oxygen for their best flocculating action, since the gelatinous precipitate is already oxidized. Ferric floc has been noted at pH values as low as 3.5, therefore, its range of coagulability is wider than that of copperas. These coagulants successfully treat soft, highly colored waters at low pH values. Ferric salts are much more corrosive to handle than is copperas. Some studies have shown that when compared on an equivalent basis of iron content, all ferric salts are of equal coagulating power. Displaying better floc forming ability than copperas, ferric salts are handicapped by their higher cost per ton. An over-all comparison by jar and plant tests is the best arbiter of the most economical choice.

**Sodium Aluminate.** Sodium aluminate, a compound prepared by causticizing alum, is useful as an auxiliary coagulant

along with alum or copperas to promote floc in difficult cases. It precipitates the aluminates of calcium and of magnesium, thus softening the water simultaneously. Its cost prohibits wider use.

**Dosage Adjustment.** The coagulant dosage required at a given plant is dependent on a large number of factors, some of them unmeasurable. Therefore, it is impossible to calculate accurate coagulant dosage by any theory or formula. Dosage is regulated by noting the clearness of the water in the taps, on the filters, and entering the coagulating reservoirs. If turbidities higher than about 0.5 p.p.m., an approximate limit for consumer notice, appear in the plant effluent, the cause may be either in filter operation or in faulty coagulation. The latter can be evaluated by noting the character of water applied to the filters. Its turbidity should generally be under 15 p.p.m.; the clearer the settled water, the more sparkling the filter effluent. Poorly maintained filters require a clearer influent to produce a clear effluent. In all cases, the water applied to filters should be without unflocced turbidity; floc particles may be small but the spaces between them should be clear. At times when the floc is barely visible, its presence may be readily detected in a glass vessel by streaking some drops on the outside of the container and looking through them as a magnifying lens. If the applied water contains uncoagulated turbidity, the chemical treatment and mixing should be examined. The first impulse during troublesome periods is to increase the chemical dosage; this generally is an effective move but should not be made a permanent substitute for poor mixing, inferior conditioning, or injury to floc on passage to the filters. Improper dosing and mixing can be ascertained by departure from normal of the entering floc bank or cloud at the coagulating reservoir inlet. Breaking down of floc en route to filters can be recognized by noting an increase of size range of the remaining particles over that in the exit end of the coagulating reservoirs. There will be much small floc formed at the expense of the larger particles. Basin maintenance is an important item in settled water quality.

**Conventional Settling Reservoirs.** Coagulating reservoirs primarily provide the retention time required for floc particles to settle to the bottom mud zone. An increasing practice is to provide flocculating equipment, generally mechanical, at the entrance end. Flocculation by structural features is only rarely designed. Retention periods vary from one hour to 30 hours; a fair average is from 4 to 6 hours. Insufficient detention will be evident from excessive floc carried to the filters. Not only must the reservoir volume be ample, but the velocity of flow must be kept low, somewhere in the order of 0.01 to 0.03 feet per second. This provision is met by allowing sufficient cross-sectional area.

Short circuiting of the water must be carefully avoided. This tendency in existing basins may be studied by observing any long-shooting course of floc and by the paths of submerged floats. Short circuiting in a basin may be studied experimentally by dumping a small amount of common salt or a dye, usually uranin, into the influent and from periodic samples of the effluent noting the actual recovery of chemical as compared with ideal displacement. Appearance of threads of dye should be noted, as these give evidence of definite currents. Every operator should make a dye test on his basins as the results usually are strikingly clear and revealing. Remedies of short circuiting consist in controlling the distribution of the influent and erecting baffles at strategic positions. In baffling, care should be taken to avoid breaking floc. Flow into the reservoir should be distributed across its whole cross section. Shooting flow through a sluice should be avoided unless the reservoir is so large that this local projection is soon mingled in the general slow advance. Corrective devices consist of influent launders, baffles, and orifice walls. The first distributes the water at the surface only. The effectiveness of baffles depends on their size and location. An orifice wall consists of four inch or larger holes through a wood wall, filling the entire cross section to insure streamline flow. Depending on its relation to the progress of floc conditioning, eddies may aid or retard coagulation;

once conditioning is in effect completed, these disturbances should be avoided. Occurrence of eddies may be observed at the turn in around-the-end basins and at the outlet gate.

The effluent gate, if located near the surface, should be protected by a curtain wall to screen off floating debris and algae mats; if submerged near the bottom, it should be behind a high sill to retain settling mud. The protection by such a sill against unloading or major mud slides is doubtful since the sludge bulk, being heavier than water, attains momentum and preserves its entirety in climbing over the obstruction. Basins, therefore, should be cleaned frequently.

The conventional basin has a sloping floor and central gullet into which the coagulated deposits are flushed by a high pressure hose. The washings then flow to waste by gravity or to a sump from which the mud pump takes suction. This sump is best located at about one third the length of the basin as the mud is higher and stiffer at the influent end. Basins are drained for cleaning two or three times yearly. Modern basins are provided with continuous desludging equipment. In the clarifier type, an elevated bridge containing a driving mechanism slowly pulls a spiral rake over the bottom of the reservoir; sludge is worked to a central sump for removal by diaphragm pumps or by gravity. In the manual or gravity type, low-level sludge blow-off valves are placed about the walls of the basin; these are opened daily by the operator. Sufficient slopes must be provided in the floor for this scheme to function. Clean basins allow lower velocities of flow, longer retention time, and less eddying than when space is filled by mud, thus facilitating sedimentation. In some plants sludge deposits, on decomposing anaerobically, impart taste and odor or release bacteria to the water, especially when scoured by a high rate of flow. Sludge may be sweetened by treating the water with activated carbon. Basin muds in a lime softening plant may have a strong odor yet not affect the water passing above.

In the passage from the coagulating reservoir to the filters,

long travel and sharp corners should be reduced to a minimum to prevent breakage of floc. A short straight line path from the basins to the filters is desirable.

Whenever floating scum and algae are found, they should be raked off. Algae growths on the walls may be prevented by white-washing from the surface to several feet below the water line with a slurry containing three parts of lime and one part of copper sulfate; after application, the surface is sprayed or painted with a 5% copper sulfate solution to produce a fully exposed algacidal surface on the coating. Dosing the water with copper sulfate solution or dragging bags of crystals through the reservoirs is sometimes done. Chlorination generally remedies algae infestations.

**Sludge Blanket Type Plants.** The operations of mixing, conditioning, and settling may be consolidated into a single unit with marked economy in space requirements and construction costs. According to manufacturers' claims, quality and performance are not sacrificed by this compact arrangement, but comparative instances are known in which the conventional settling basin type of plant function with less attention to details of operation and with greater economy in use of chemicals. As all waters cannot be treated economically in a high rate plant, the application of the sludge blanket tank should be preceded by a careful pilot test. In this design, two beneficial procedures are employed, namely, the addition of the coagulant in the presence of considerable previously formed floc and the passage of the water through an expanded sludge blanket. The first step utilizes the helpful action of return sludge by furnishing seed for new floc growth; the second feature intimately contacts the water with coagulum to accelerate chemical reactions and to function as a roughening filter, or prefilter. Used in connection with lime softening, the effluent may approach carbonate stability to a greater degree than does the effluent from the conventional coagulation basin. In a commercial unit chemical, influent water and sludge are mingled in a central

zone, then mixed by a propeller for about 10 minutes, and discharged through the previously formed sediment. Direction of flow through the sludge is upward to keep the blanket in suspension. In a properly operating unit, a sharp, upper surface of the sludge can be seen through the supernatant water. Manufacturers' variations of this device appear under various trade names; two such plants are shown in Figures 11 and 12.

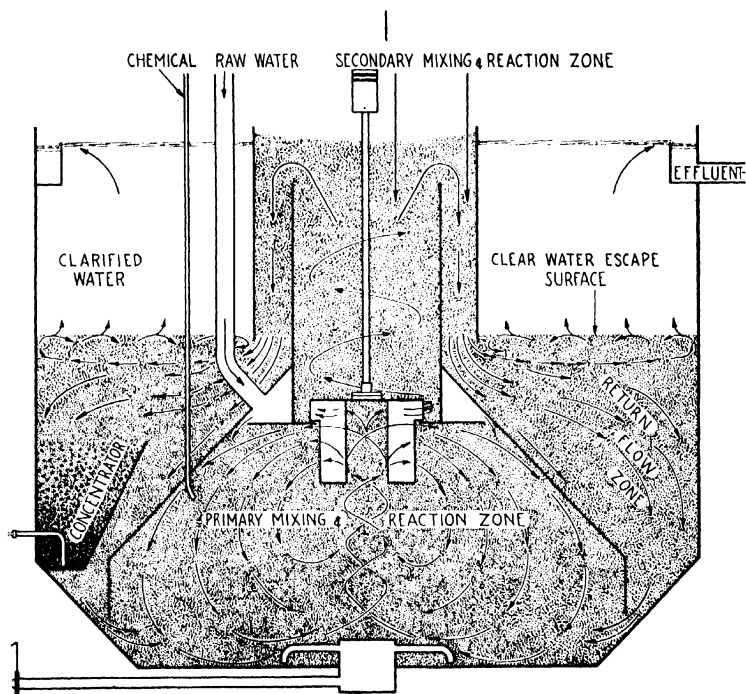


FIGURE 11

Accelerator Flow Diagram

(Courtesy of Infilco, Inc., Chicago, Ill.)

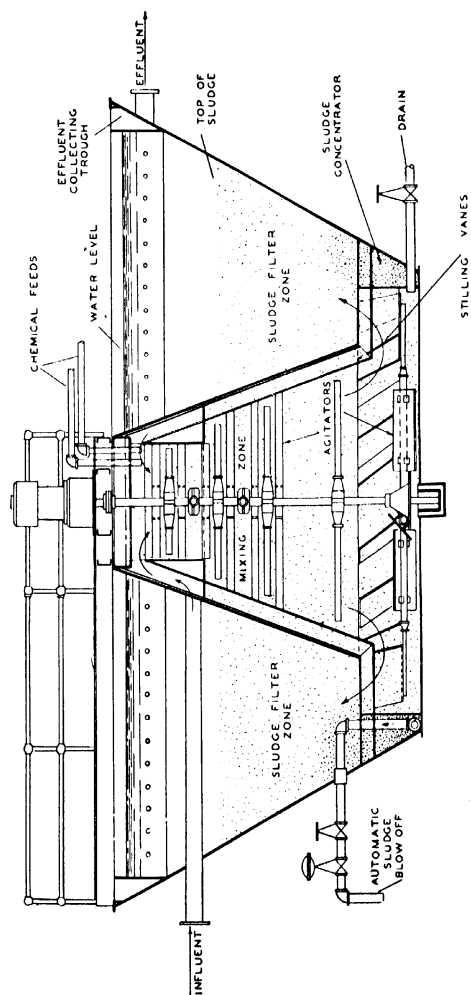


FIGURE 12

Vertical-Type Spaulding Precipitator  
(Courtesy of the Permutit Company, New York, N. Y.)



**Tests.** Tests should be routinely made of the characteristics that coagulation is intended to improve. Samples should be taken from influent and effluent; if significant steps occur in-between, these also should be sampled. Turbidity is the basic property to examine, as turbidity reduction is the primary object of coagulation. Where color reduction is an objective, it should be measured. Alkalinity and pH data are helpful. With lime treatment these values are needed to regulate lime dosage. In plants where coagulant action is sensitive to pH value, its determination is needed to adjust chemical dosage. Jar tests, as needed, should be performed to study changes in character of the water; with experience the need for these tests will be reduced in frequency. Bacterial tests usually show 85 to 99% reduction.

Possibly more important than laboratory control, is the frequent routine inspection of the action in the operating units, mixing basin, flocculator or conditioning devices and basins. Hazy appearance of the basin effluent should be corrected by adjusting the chemical dosage, as guided by laboratory tests including jar tests and experience. Swirl zones, created by structural disturbances, should be eliminated if possible. Plant inspection is especially important during periods of low water temperature, when floc formation is considerably retarded.

**Dry Feeding Equipment.** Devices for feeding chemicals fall into two classifications: dry feeders and solution feeders. As its name indicates, a dry feeder measures out, usually by volume, a desired amount of powdered chemical per unit of time, and delivers it to a hopper where it is dissolved or dispersed before applying to the water. For the small plant, dry feeders are usually preferred because of their reliability and simplicity. The operator is spared the detail of dissolving the chemicals.

Particular makes of dry feeders may use the following mechanisms:

- a. Turn table, fed from a hopper with an adjustable opening.

Its principal adjustment is by altering the position of a scraper which deflects material from the edge of the pile on the turntable.

b. Adjustable lost motion which controls the width of opening of a shutter that admits the chemical.

c. Screw conveyor with speed of rotation varied by an adjustable pawl.

d. Oscillatory shelf having an adjustable amplitude under a stationary hopper.

e. Vibratory hopper and trough. This type can accommodate wide ranges in amounts with considerable accuracy.

A weight-type feed machine is also available for large plants. In Chapter 18 calculations are described for checking the delivery rate of dry feed machines and a chart, Figure 44, is given for convenient application.

**Solution Feed.** A solution feeder is always preceded by a dissolving tank. As its delivery depends on hydraulic principles, this class of feeder is readily adaptable to automatic regulation in response to fluctuations in rate of flow in the plant. Solution feed devices are of the following types:

a. Pressure pot and orifice. The chemical solution is prepared in a closed vessel. A line carrying water under pressure from a point downstream below an orifice inserted in a union, or a like obstruction, enters the bottom of the vessel. A tap communicates higher pressure from above the orifice to the top of the pot. The difference in pressure causes the solution to move in proportion to the rate of flow. An operating difference in pressure may also be obtained across two Pitot tubes, pointed in opposite directions inside the pipeline.

An interesting variation of the pressure pot system consists in mounting a small tank filled with oil, which acts as a fluid piston and visual indicator, in advance of the larger tank containing the chemical solution. Under head from the high pressure tap, oil enters the solution tank through a sight glass where the rate of feed is determined by timing the drops of ascending

oil as it displaces chemicals that enter the water system through the low pressure connection. The larger volume of the chemical solution tank prevents entry of oil into the water system. When the reagent is completely emptied, as indicated by the presence of water only in the gage glass, the oil is transferred back to the smaller tank, and a fresh charge of chemical solution added to the larger tank.

b. Proportional pump. A plunger type pump directly connected to the plant pump or to a water meter in a pressure line injects chemicals proportionally to rate of flow. Solution feed pumps, with adjustable speed and piston throw, but without automatic connections, are widely used at small plants. For corrosive liquids the chamber of the pump is all rubber or plastic.

c. Float tank and orifice (see Figure 24). Solution level over an orifice is maintained constant by a float valve; solution passing the orifice is diluted by a carrying stream on the way to the point of application. Variations in rate of feed are obtained by varying the float position, the size of the orifice, and the strength of solution. The float tank may consist of a toilet flush tank and valve. An orifice may be formed at the end of the line by means of a needle valve.

d. Floating orifice. By attaching an orifice submerged below the surface of the chemical solution to a float, a constant head of solution is maintained as the tank empties, thus securing constant rate of feed. One kind uses an orifice or circular weir attached to a sinker which is lowered at a desired rate by motor; in this way the tank level is lowered uniformly.

e. High head orifice (see Figure 25). This device can be built readily at the plant, using an oil drum and about 10 feet of vertical drop pipe. The drum is mounted on a stand, at sufficient elevation above an orifice placed at the bottom of the drop pipe. As the drum empties, the effect of reduction in head is diminished by the presence of the column of solution in the drop pipe. By elementary hydraulics the relative changes in

rate of flow are only one-half the proportionate changes in head over the orifice. Since the variation in head is restricted to relatively narrow limits by elevating the drum sufficiently and by maintaining the solution between fairly close full and empty marks, about 3 feet apart, the discharge of chemical can be made as nearly uniform as necessary.

f. Constant head siphons. The basic principle underlying devices of this type is the entry of air through a sucker tube at some desired level above the outlet opening. Several arrangements are shown in Figure 13. A pneumatic trough is also

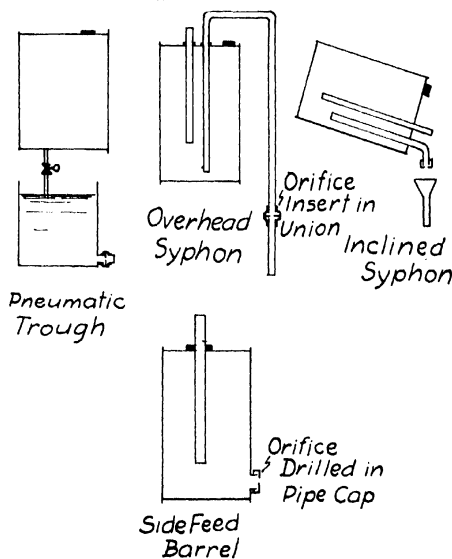


FIGURE 13

Some Constant Head Arrangements for Chemical Feed

included on account of its similarity. In this scheme the top solution tank becomes air bound except when the level in the orifice tank below exposes the tip of the tail tube; on sucking

air, contents of the top tank empty until the seal is closed again.

**Feed Requirements of Different Coagulants.** Lime is fed only in the flaked form, either in dry or wet feed. In a large plant, purchase of lime as quicklime is a decided economy but this must be slaked before use, usually by solution feed. Alum, copperas and ferric sulfate may be fed using either wet or dry methods. Lead lined or other corrosion-resisting piping is necessary, as solutions of these coagulants are decidedly acid. Hydrated ferric sulfate dissolves readily; but the anhydrous variety, being accompanied by a noticeable rise in temperature due to heat of solution, dissolves best when only a small amount of water is used. Ferric chloride, being hygroscopic or water absorbing, is fed by solution exclusively; commercially available forms are liquor, crystals, and anhydrous.

Dry chemicals are most conveniently stored in bins or bags on a floor above the feed machines. If the hopper opening is on this upper floor level, emptying a chemical charge into the machine is facilitated. Pieces of string, chips, paper and other trash should be kept out of the feed bin and hopper to avoid clogging of the machine.

## CHAPTER 8

# FILTRATION

**Theory of Action.** Filtration is the act of passing water through a sand or similar bed for removal of previously coagulated suspended matter remaining after sedimentation. The effective performance of a rapid sand filter depends more closely upon the proper prior coagulating treatment than upon the details of the filter unit itself, because imperfectly prepared water will inevitably filter poorly. Early filters for water were used with low turbidity sources; coagulation was not employed, rates of filtration were low and cleaning was done by stripping the top sand crust. These slow sand filters required enormous sand bed areas and were unsuitable for turbid waters.

In the rapid sand filters, a final polish is given to the water by the removal of residual floc carried over from the coagulation reservoirs. The clearer the applied water, the brighter will the filter effluent be. Residual turbidity of the filter influent should be no greater than 15 p.p.m., preferably less. By passing through sand, suspended matter is removed, even though its size is much smaller than the voids between the sand grains. This retention is caused by a bridging action by which the particles become wedged by the first few inches of sand, in much the same manner as freely floating logs become jammed in a stream. Since the floc is retained as a mat, it serves as part of the filter membrane, however its presence is not usually necessary, as a clean filter gives a clear effluent. A disadvantage of the floc mat is that at high loss of head it is liable to crack and allow pieces to penetrate deeply, possibly through the sand. Aside from the wedging action, theories of filter action also are based on a surface adhesion effect of the sand particles for the

coagulum and on electrical attractions between sand and floc.

Materials removed by a filter normally consist of floc formed from chemical agents in removing turbidity, bacteria, iron, color and hardness. In a lime softening plant, additional softening action is accomplished by a reduction in alkalinity through the filters; this is due to the promotion of precipitate on the filter surfaces.

## STRUCTURE

The structural units of a rapid sand filter include (a) the filter compartment, (b) trough, (c) sand layer, (d) gravel layer, (e) underdrains, (f) piping, and (g) gages and controller. Figure 14 shows typical construction. Clear water storage is frequently provided directly underneath the filters, otherwise the effluent drains to a filtered water reservoir.

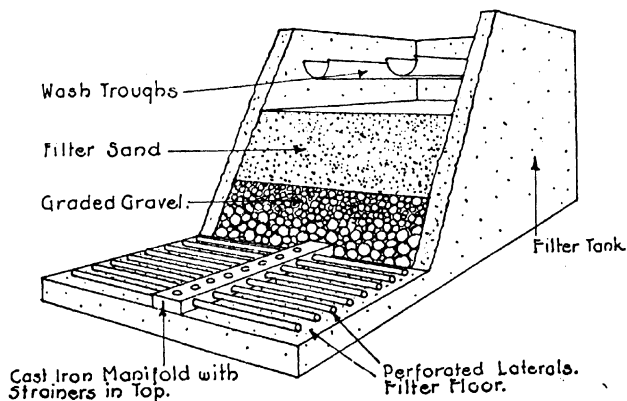


FIGURE 14

Cut-Away View of Gravity Filter Showing Underdrains and Filter-Bed

(Courtesy of National Lime Association, Washington, D. C.)

**Filter Box.** In the small plant, circular wooden tanks are widely used; in large plants, filters are concrete boxes built for capacities from 0.5 to 6 MGD. A large number of filter units permits flexibility of output and enables filters to be cut out of service for cleaning and servicing. Wall surfaces in contact with the sand are sometimes roughened by the gunite method to prevent flow between the walls and the sand bed. It should be impossible for unfiltered water to bypass the sand layer through cracks or porous concrete walls. If the filter wall does not extend above the floor level, a curb should be built at the filter edge so that sweepings and floor washings do not fall into the filter.

**Troughs.** Steel troughs are generally used in the circular wooden filter; in a concrete filter box the troughs are also reinforced concrete. Their main purpose is to collect up-flowing wash water and discharge it to a central or terminal gullet which is opened to a drain. The top edges of the trough should be installed and ground to a uniform elevation to drain off all parts of the washed filter evenly, in this way avoiding a tendency for spotty washings. Filter troughs are tested for exact level by opening the drain; the tops of all troughs should appear at the water surface at the same instant. No part of any trough should drain longer than any of the others. If this is not the case, the high spot should be dressed down, with a carborundum stone or a portable emery wheel, to a common level. Bottoms of the troughs are sloped to empty residual washings and to provide increasing cross section to accommodate additional portions of wash water toward its gullet end. As the gullet also serves to admit settled water for filtration, the troughs serve a minor purpose of distributing the applied water over the filter area.

**Sand.** Sand, the heart of the filter unit, acts as the filter medium. A bed 30 inches in thickness is usually provided, however tests show that a twelve-inch layer effects complete filtration. A *freeboard*, that is the distance from the top of the sand



bed to the top of the trough, usually equals the rate of wash water rise in inches per minute. It allows for the expansion of the sand during a wash.

The sand size is of the utmost importance. From the standpoint of resistance to flow of water, the smaller grains are relatively much more obstructive than the larger sizes; hence the true average size of grain, or the "effective size," will lie in smaller diameter grain groups. Tests indicate that the size which separates the coarser 90% from the finer 10% of the sand controls the hydraulic behavior, consequently this is called "effective size." Sand size distributions are obtained by a standard sieve analysis, the results of which are plotted graphically. So called "logarithmic probability" paper is the best for this purpose, but logarithmic paper is widely used; their advantage is in smoothing out the curve. From such a graph the effective size is read. Similarly, from the plot, the size is found which separates the finer 60% and the coarser 40% of sand; this size has not received a name. The ratio of this latter size to the effective size is called the "uniformity coefficient." This quantity measures the distribution or dispersion of grain size, the higher the value the greater the range of size. A perfectly uniform sand would have a uniformity coefficient of one.

Consideration of prevailing practice forms the basis of sand specifications. Effective size should be between 0.35 and 0.55 mm.; uniformity coefficient between 1.5 and 1.7; even larger sizes are favored where adequate coagulation is assured. Larger sizes permit easier passage of water, but of primary importance is the fact that longer filter runs are possible between backwashing. Filter sand of effective sizes below the lower limits specified clog quickly, necessitating frequent washing and an excessive proportion of wash water. Flat grains have greater buoyancy and so are easier to wash than round grains; likewise, they pack more loosely, allowing greater voids for the water to filter through. Sand should be high-quality silica having less

than 5% of material soluble in 10% hydrochloric acid. Grains larger than 1 mm. are not permissible.

*Anthrafilt.* Anthracite coal screenings are being marketed under the name "Anthrafilt" competitively with sand for filter media. Their main advantage is easier expansion at low wash water rates, as a result of their light specific gravity; thus economizing on wash water consumption. Larger size angular grains with diameters up to 0.73 mm. and uniformity coefficient near 1.60, are used which permit floc penetration down from the top deck, the result is longer runs and higher filtration rates than with conventional size of heavier sand. Wash rates must be carefully controlled, otherwise much coal may be floated over into the troughs. Coal grains do not scour as effectively by collision as does sand, hence a supplementary surface washing device is generally advisable.

Other special filter materials, of interest particularly to industrial water supplies, are crushed limestone, useful in stabilizing the alkalinity of lime-treated water, and magnetite which is cleaned continuously by a traveling electromagnet and automatic flushing carriage. Where slight increase in dissolved silica, such as caused by contact of alkaline lime-treated waters with sand is undesirable, as for boiler feed, alternate filter material is employed.

**Gravel.** The gravel layer acts as a support for the sand and also distributes the wash water uniformly from the underdrain jets. An eighteen-inch thickness is commonly used; the gravel, varying from 4 inches to pea size, is placed in four or five layers. Bronze screens formerly laid between the gravel and sand zones are now omitted. Filters are now being successfully pioneered in which both the gravel and underdrains are replaced by a porous false floor made of carborundum.

**Underdrains.** The underdrains, a critical feature in filter design, serve two functions: (a) to collect the filtrate and conduct it to a central passage leading to the filter controller and

(b) to deliver back wash underneath the gravel. A system adequate to fulfill the second objective obviously satisfies the first purpose since during back wash a much higher rate of flow is required.

Ideally, the underdrains should distribute wash water evenly over the entire filter bottom. However, since most drains have jets or openings spaced at intervals, this requirement must be relaxed to require that the flow from the jets is uniform. The gravel layer serves in such cases to diffuse the jet action and so make the upflow uniform under the whole sand area. If the flow of wash water is not even throughout the filter area, some parts will be well washed at the expense of poor washing elsewhere. In spots violently overwashed, the gravel layer will be displaced or overturned by jet action and when upward flow stops, sand will take the place of the gravel. Cratering of gravel may be caused over broken strainers or near the central manifold where wash water pressure is highest. When the sand is insufficiently washed, floc will adhere to the sand, cementing adjacent grains together. Bacteria will remain relatively undisturbed in poorly washed areas, whereas in thin spots caused by jet action, the water may not receive sufficient sand filtration. Sand clusters may grow in size to mud lumps over a foot in diameter. Net filter area is thus reduced. Initial formation of mud lumps starts a vicious cycle, unless checked by attention during operation.

Available underdrain types include: (a) perforated pipe laterals, with or without a false bottom, (b) slotted tube laterals, (c) perforated brass plates or strainers on ridge and valley floors, (d) precast hollow concrete blocks over laterals, and (e) porous slabs of aloxite or carborundum. The first three types are connected to a central manifold; the third type is in effect a patented defecting device used in connection with perforated pipe laterals; the last type is one that eliminates the need for gravel.

As its name indicates, a perforated pipe underdrain consists

of a pipe spaced on six- or eight-inch centers, perforated underneath with one-quarter- to one-half-inch openings, 3 to 8 inches apart, staggered on a  $60^\circ$  angle. The total area of these orifices is commonly taken as 0.2% of the filter bed area. Corrosion resistant jets are sometimes inserted and the perforations faced upward. A disadvantage of uniformly spaced circular orifices is that delivery along the pipe length is not uniform, the far end discharging more than its proportionate share of wash water. Concrete blocks are intended to reduce this effect somewhat and also to spread the wash laterally between rows of tubing. Simple perforated orifices can be made to distribute water evenly throughout the pipe length but the spacings must be concentrated at the influent end and spread at the far end, in accordance with a definite pattern. Rather than introduce this complication, strainers are still drilled with uniform spacing for use with or without patented blocks or false floors.

Slotted tube laterals are perforated by a special punch and dies rather than by drilling. By using brass tubes, these underdrains can be quickly and economically made. One design of slotted orifice consists of a uniformly spaced short transverse slit with the downstream lip protruding inward to act as a deflector to guide water through the orifice. Such a tube, illustrated in Figure 15, gives virtually uniform discharge throughout its length.

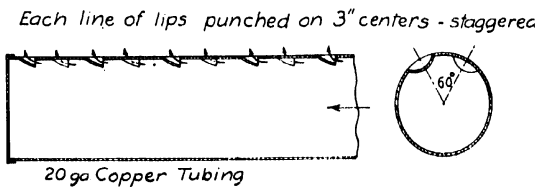


FIGURE 15  
Delery Filter Underdrain Tube

When installing pipe or tubular underdrains, the openings are usually pointed downward to reduce jet action through the

gravel. In this position, sufficient space should be left between the bottom of the pipe and the filter floor to insert the largest size gravel used. Otherwise, should the underdrains be too close to the floor, a channel will exist which will conduct the wash water to the end of the pipe. This effect is particularly noticeable in the lipped type orifice when improperly installed. Channelling can also be prevented by turning the orifices upward.

Brass strainer plates over ridge and valley floors act in principle similarly to uniformly drilled orifices.

The far end of the manifold feeding the underdrains is provided with an air release to prevent air binding at the extremity.

**Piping.** Piping is provided to supply settled water, to pass filtered water, to backwash, to waste spent wash water, and to drain the filter bed. The settled water passages should keep velocities below two feet per second and avoid sharp bends to minimize breaking of residual floc. Small plants built with filters abutting the settling reservoir are advantageously arranged. The wash water line should be ample to carry a high velocity wash, and the drains liberal enough to carry off the waste wash water without backing up to the trough tops. A small waste line connects the filter manifold to the drain; this allows filtered water to run to waste when required and allows the water level to be lowered below the troughs or entirely emptied for observations or repairs. Care must be taken to avoid return flow of washings from other filters through such a connection.

Hand-operated gate valves are used in small plants; hydraulic cylinders are used for operating medium size and large plants. Vertical installation is desirable, when possible, to ease operation and reduce wear. Packing should be maintained watertight. Valves and cocks are best lubricated with tallow. Hydraulic valves should never be slammed as this mistreatment invites sticking. A small, float-controlled sump pump at the bottom

of the pipe gallery is sometimes installed to remove incidental leakage.

**Gages and Controller.** Gage and pipe connections for a typical rapid sand filter are indicated in Figure 16. A loss of

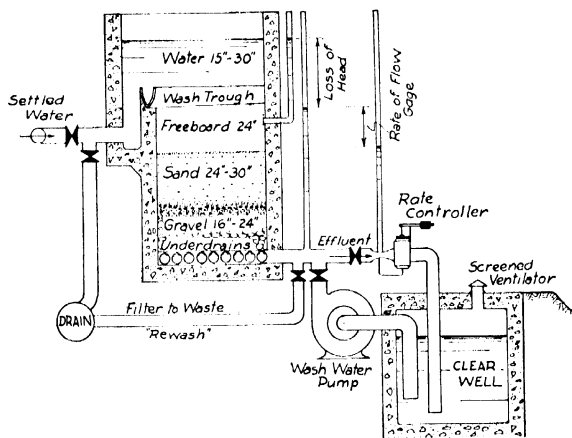


FIGURE 16

Diagram of Filter and Gage Connections

head gage measures the drop in pressure across the filter bed. In its simplest and most reliable form it consists of two glass tubes, one connected to the filter above the sand and the other tapped in the effluent pipe in advance of the controller. More conveniently read gages show loss of head on a float- and cable-operated dial or by various other mechanisms. Gages indicate the condition of the sand bed by measuring its frictional resistance to the passage of water. Loss of head through the filter depends upon size of sand, the rate of flow and amount of coagulum deposited on and in the top layer. Fine sand causes greater head losses than coarser ones. Loss of head varies directly with the rate of filtration. Temperatures also influence loss of head, low temperatures causing water to flow more

sluggishly, thus producing somewhat greater losses through a filter. In a given filter, determination of the loss of head is useful primarily to indicate the impeding effect of the top mat of strained out floc. When this becomes great enough, the sand must be backwashed.

The rate of flow gage indicates the delivery of the filter by measuring the pressure difference across an orifice or venturi tube in the effluent pipe. Its connections are invariably taken off from the venturi of the rate of flow controller. The divisions on the face of the gage ordinarily are non-uniform because of the relationship between pressure drop and the flow through an orifice or venturi. Some specially shaped floats in a mercury chamber may be used so that the rate of flow gage graduations are made uniform. This gage enables the operator to make adjustments in rate of production and to keep check on the amount of water passing through the filter unit.

The rate of flow controller maintains filter delivery at a constant rate by automatically opening a valve to compensate for increasing loss of head due to floc deposition on the bed and for variations in the water depth on the sand. One form consists of a diaphragm-controlled balanced valve, built on the tail piece of a short venturi meter, as shown in Figure 17. Settings for a desired flow are made by weighting the diaphragm either hydraulically or by a loaded lever. The controller in the illustration may be fitted to cut out a filter from service automatically by connecting a counter-balanced high-level float in the clear water reservoir, through a stiff rod, to the right end of the weighted beam. When the reservoir level reaches the desired height, the float will become submerged and gradually reduce the rate of filtration by buoying up the weighted beam, until closure of the balance valve is completed. In many large filter galleries, the rate of flow controller is actuated by a master controller in response to height of water in the clear water reservoir or flow to the high service pumps.

A rate of flow controller assures the operator that the filter

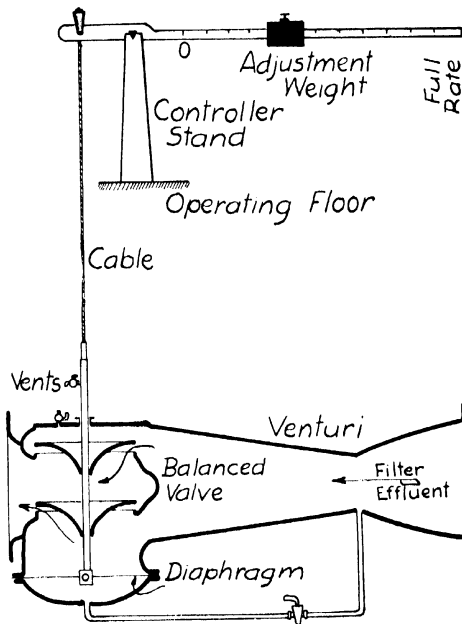


FIGURE 17

## Filter Controller, Simplex Type

*Principle of Operation.* On the upper side of the flexible diaphragm, pressure from the recovery or tail section of the venturi pushes downward. In the bottom chamber, the smaller pressure from the venturi throat pushes the diaphragm upward. As a result, the diaphragm would move downward except for the lifting action of the counter weight, which is set at the desired rate on the calibrated lever. The dual discs in the balanced valve allow opening and closure independent of pressure changes.

will deliver at a desired rate throughout its run. By gradually reducing its throttling action as the floc mat accumulates, it avoids sudden impact which might crack the deposit in spots and allow turbidity to penetrate deeper into the sand or even through into the effluent. Some controllers are provided with a reset device which closes the control valve to zero for the



start of a new run in order to protect the filter against an initially wide open flow when starting afresh and preventing a loss of mercury from the gages.

For convenience in operation, all but the very small plants centralize the gages and control switches at an operating table, one for each filter unit. In addition to the loss of head and rate of flow gages, the table houses the valve controls for influent, effluent, backwash, drain and waste. For hydraulically operated valves, the position of the gate is indicated on a dial actuated by a bead chain attached to the tail rod of the cylinder. A totalizing meter may be included to show the quantity filtered from the beginning of the run. Other gages are sometimes installed. A continuously flowing effluent sample is drawn through an observation glass by means of an aspirator. A sampling cock enables water to be drawn off for bacterial and chemical tests.

A plate glass window through which a submerged one hundred-watt light can be viewed on the bottom, is sometimes built over the clear well.

## OPERATION

**Usual Practice.** Conventionally, the usual rate of operation of a filter is 2 gallons per minute per square foot of sand surface. This is equivalent to 125 million gallons per acre per day or to a uniform vertical velocity of 3.2 inches per minute in the applied water. This nominal rate may be exceeded if the coagulation and settling has been well performed; some filters are intended for operation at 3 gal./sq. ft./min. Filters should be run uniformly by cutting out extra units during periods of low consumption and by utilizing the clear water reservoir during peak loads. Filter runs may be ended in one of two ways; (a) the loss of head, after steadily mounting, reaches a value between five and eight feet, the filter rate falls and the controller opens wide and (b) the filter, after a run of hours

or several days without significant rise in loss of head, begins to show turbidity in the effluent. During cold weather, air binding may sometimes interrupt a filter run, but after a short backwash in order to remove accumulated air bubbles from the sand, the run ordinarily may be resumed.

The length of run, or time between backwashes, varies from about six to several hundred hours. Neither of these extremes is desirable. Very short runs may indicate poor coagulation, too fine a sand or cemented sand lumps; in this case the consumption of wash water is excessive. Unseemly long runs may indicate that sand grains are too coarse, from selection or from coatings; the effluent then shows appreciable turbidity and may allow floc to break off and penetrate through the bed.

Permissible turbidity of filter effluent is commonly limited by operators to 1.5 p.p.m. Above 1.0 p.p.m. turbidity, the water shows a slight haze visible in bathtubs and in the inverted bottle-type of water coolers. As the production of a clear finished water is the primary object of a filter plant, a turbidity meter suitable for making determinations in the range of 0 to 5 p.p.m. turbidity, should be a part of the equipment. Aside from furnishing a numerical value for rating the plant effluent, it also supplies an index for observing changes in plant operation below the level of visual recognition. Very clear filtered waters are essentially free from bacteria.

**Head Conditions.** The diagram, Figure 18, shows how the loss of head is largely concentrated in the top few inches of sand bed when the filter is dirty and explains the condition referred to as "negative head." The diagonal reference line locates the depths to which the hydraulic grade lines, or pressure lines, refer. To find the head prevailing at any level in the sand or gravel, locate this level along the reference line, then project this point vertically to the hydraulic gradient. Such projections are clearly marked off in the diagram to correspond to the contact planes between sand and gravel, and gravel and under-drains.

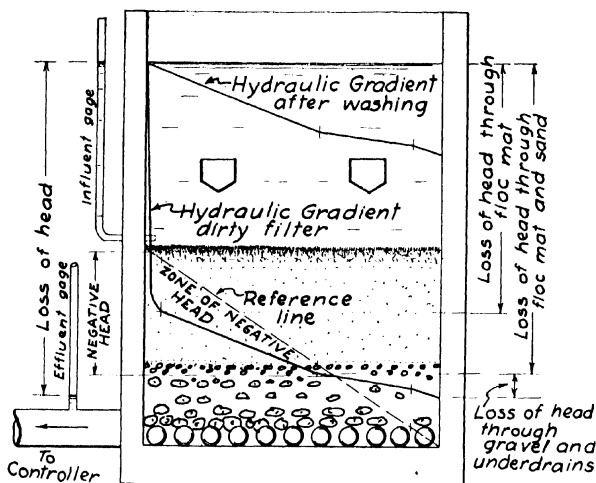


FIGURE 18

## Pressure Conditions in a Rapid Sand Filter

In a clean filter, the loss through the sand increases fairly uniformly with depth as the hydraulic gradient after washing indicates. When the filter becomes dirty, the floc mat and the first few inches of sand into which the coagulum has penetrated increases enormously in resistance to flow. Below this clogged portion of sand, further loss of head is practically the same as in a clean filter. This similarity is noted by the parallelism of the two hydraulic gradients once below the top strip of sand.

A partial vacuum forms whenever the hydraulic gradient stands below the point at which a pressure is measured. In a very dirty filter as shown, such a point is first reached where the gradient crosses the reference line in the floc-packed surface layers. Negative head continues to a point in the gravel layer where the gradient crosses over above the reference line. At this point the negative head is a maximum, since the bottom of the

filter and the effluent pipe act as a draft tube to pull water through the zone of negative pressure. In order to evaluate the amount of negative head precisely, a pressure traverse must be made through the filter. However, for practical purposes, the negative head may be taken to equal the distance that the level in the effluent gage stands below a point about six inches underneath the sand surface. When the hydraulic gradient through a dirty filter drops below the level of the effluent sampling cock, air will be sucked in if it is opened instead of water being discharged.

**Backwashing.** Filter washing is accomplished by closing the filter influent and effluent valves, draining off the top water to the trough level, slowly admitting wash water to jostle and scrape the sand grains together, and finally increasing the wash gradually to full rate which is maintained until the sand bed is sufficiently cleaned. On completing the wash, the wash and drain valves are closed, settled water is admitted to the troughs and brought up to operating level, and then the filtered water valve opened. The practice of opening a so-called rewash or filter to waste line for a short initial period, in order to lay down the beginning of a floc mat, has been found unnecessary. Well coagulated and settled water will filter clearly from the start of a filter cycle. During the wash, the filter should be inspected for any local disturbances or dead spots and prodded with a rake to discover and break up lumps.

The period of full rate backwash, usually taking about five minutes, should be sufficient to clean the sand. Sometimes adequacy is judged by the appearance of relatively clear spots in the rising wash; a better index is to wash until the turbidity in the drainings is down to 75 p.p.m., which value gives the maximum wash water economy. The amount of wash water will vary from about 0.5 to 10% of the water filtered. It should not be greater than 2.5%.

**Wash Rate.** The rate of wash water application is important in proper scouring, in clearing away heavy organic

growths, and particularly in maintaining satisfactory conditions within the filter medium. A sluggishly applied wash will require an excessive period of washing and probably fail in cleaning off the filter sufficiently to avoid later trouble. A rising velocity capable of expanding the sand bed by 50% of its depth is widely recommended. The amount of water required for this flotation effect may be calculated from the sieve sizing of the sand and its specific gravity, or better yet may be indicated by noting the position of a float, heavy enough to sink in water, but light enough to be supported by the sand layer. Sand expansion indicators of this type are sometimes installed in a completely fitted plant. An improvised type may be made from a waterproof light, either plug-in or flashlight, attached to a rod to locate the surface of the expanded sand. A 50% bed expansion is generally equivalent to washing at about 8 times the normal filtration rate, or a rise of about 25 inches per minute. A slower wash is permissible in colder water in which increased specific gravity and viscosity enhance the buoyancy of sand grains. The backwash rate may be measured by closing the drain valve while the filter is being washed and then noting the inches rise per minute of the water level in the filter box. Most of the older plants are not provided with piping and underdrains large enough to carry an eight times rate or to allow 50% bed expansion. This deficiency may be corrected either by changing from sand to coal for the filter media, or by providing supplementary washing fixtures. Due to much lower specific gravity, coal is backwashed at lower rates with resultant savings in wash water.

Auxiliary washing systems may use air, applied directly through the underdrain system or above the sand-gravel interface; or use high-velocity water jets applied near the slightly expanded sand surface. Water jets, presently favored, may be staggered on a stationary grid or may be spaced along a slowly revolving arm to sweep across the filter area. This type of device is said to be effective in maintaining filters clean and in

improving the condition of depreciated sand beds. In the absence of supplementary piping systems, beneficial cleansing action is obtainable by playing a high-pressure hose stream on the sand, after drawing down the water level just above the top of the bed.

**Bed Difficulties.** Inadequate backwashing due to too low a rate or non-uniform distribution, allows a residual coating of coagulum to remain on the sand grains. This material tends to stick adjacent grains together; on further standing, this colloidal material shrinks on aging and cements the sand particles solidly. This process of shrinking can often be observed in the coagulum mat and is an argument against excessively long runs. The cracks allow penetration of applied water without filtration and contact time permits the gel mass to stiffen progressively under water. The obvious preventative against this tendency is to wash the filter clean. Colloids able to cement sand grains include soil from residual turbidity, the hydrous metal oxides from the coagulants, and organic matter. Where lime softening is employed, grains grow in size and tend to lump together by the after-precipitation of calcium carbonate on their surface. This tendency may be controlled by recarbonation or by minimal dosage of sodium hexametaphosphate to the applied water. Specific deficiencies noted in degraded filter beds include (a) the formation of mud balls varying in size from millimeters to feet, (b) cracks partly through the sand found at the side wall and over the surface of the bed, (c) clogging of underdrains, (d) mounding where mud lumps interfere with wash rise at the top of the gravel and (e) inversion of sand and gravel layers above broken underdrain jets.

In addition to alertness in observing any irregularity in filter action, the operator should annually take a representative sand sample over the whole cross section of the filter to find by sieve analysis the extent to which the sand grains have increased in size due to coating. A check should also be made in the same sample for the proportion of mud lumps retained on a No. 10

sieve; these should be less than  $\frac{1}{2}\%$  by volume of the size of the sand sample.

**Sand Cleaning.** Coated or lumped sand may be cleaned either mechanically or chemically. Mechanical methods vary in labor from agitating the expanded bed by rakes, hose streams, portable submerged jets, or electrically powered propellers to removal, usually by an eduction type hopper, for crushing by wet raking or by washing through a riffle. Chemical cleaning depends on the corrosive action of strong solvents. Alum floc is removed by caustic soda, about two pounds per foot of sand area dissolved in a four-inch water layer on the sand bed. Calcium carbonate is removed by muriatic acid, inhibited to prevent corrosion, or by carbonic acid. Iron, manganese and alum coatings are cleaned off by a solution of sulfur dioxide gas. Copper sulfate solution kills and softens algae deposits for removal by flushing. Heavy chlorination, about 50 p.p.m. residual, will destroy bacterial growth and algae clumps. Injection of fairly high chlorine doses, up to about 15 p.p.m., into the wash water followed by as long a period of contact as the operating schedule allows, has kept filters bacterially clean and free from sand troubles.

**Filter Controller Calibration.** In addition to its primary function of automatically regulating the filter rate, the filter controller may also serve to meter production through the unit, provided its accuracy has been established or adjusted. If the filter has been in service for, say, 10 hours, the average effective daily rate of filtration obviously is equal to  $\frac{1}{10}$  of the sum of the hourly readings, however, the actual daily production from the unit is only  $\frac{10}{24}$  of this figure.

A filter controller may be tested for accuracy by closing the influent valve, with the filter otherwise in operation. After assurance that the influent valve is fully shut, the time in minutes taken for the water level to drop one foot is noted.

Knowing the area of the filter in square feet, the rate of flow can be calculated from the formula:

$$\text{Rate (gallons per day)} = \frac{10,800 \times \text{area (square feet)}}{\text{time (minutes)}}$$

In making this test, the measurement should be taken before the water level falls below the level of the edge of the troughs, unless a correction is made for the area occupied by the troughs. A simpler method consists in measuring the drop during a time in minutes equal to  $0.0009 \times \text{filter area (square feet)}$ ; the distance dropped in inches equals the million gallon per day (MGD.) rate. For filters smaller than 4 MGD. capacity a convenient multiple of this time should be used.

When the difference between controller setting and the actual rate is only a few percent, the correct position of the setting dial or jockey weight might be found from a calibration curve or a correct scale of positions tagged directly on the controller scale. On some makes of controllers the scale is slotted so that its position can be shifted by loosening the set screws.

*Repairs.* Air binding is especially liable to occur in winter when the cold water contains its greatest amount of dissolved gases and a slight temperature rise causes some release. This air may be expelled by a short backwash. Air binding is also induced by a so-called "negative head" which occurs when the water level in the effluent tube of the loss of head gage stands below a few inches under the top of the sand. Under this condition, a partial vacuum exists in the sand bed underneath the floc mat and dissolved gases escape causing air binding. In such a case, the filter should be cautiously backwashed, and a new run started.

Should the controller setting vary considerably from the rate found by calibration, a mechanical fault is indicated. Air accumulating in the diaphragm chamber should be released by opening the pet cock occasionally. The diaphragm should be examined and replaced if leaky. Ruptured diaphragms may be



temporarily repaired, pending replacement, by vulcanizing with an automobile tire patch.

A sticky pilot valve may be loosened by manually working or carefully cleaning with 10% muriatic acid and rinsing off. Strainers in the pressure water line should be kept clean and in good condition. Leakage past cup leathers in a hydraulic valve is indicated by creepage of the valve stem without corresponding flow to waste from the switch.

Other troubles should be referred to the manufacturer's representative.

**General Cleanliness.** Aside from being the display center of the water plant, the filter building and units should be well maintained for the sake of efficient operation. Floating debris should be skimmed off the water surface whenever present. Thin algae growth on the side walls can be removed by hosing. Persistent algae can be killed or its grip loosened by lowering the water level a few feet and spraying the infested areas with 1% copper sulfate solution. Algae growth on walls may be entirely prevented by calcimining the moist part of the wall with a slurry made from three parts of hydrated lime and one part of copper sulfate crystals, then spraying over this coat with a 1% copper sulfate solution. Pre-chlorination of settled water is effective against algae growth in the filters.

**Records.** As in any other manufacturing process, the keeping of records should be considered as a part of the operation. Systematic records permit evaluation of variations in plant units and procedures, such as comparisons of service and backwash requirement of sands, comparison of clarity in effluents from various filter units, seasonal fluctuations in treatment response of raw water and many other valuable points whose value would be largely lost unless regularly recorded. Records also have a legal standing in event of controversies; they provide a basis for defense of the plant operator whenever local upheavals or epidemics are suffered. In a small plant, these records may be conveniently included in a general plant log;

in a large plant, a separate entry sheet may be used for each filter, from these the daily log for the filter gallery is posted.

Basically, the desired information for each filter unit in a large plant includes hourly reading of rate of flow, loss of head, number of hours in service since last wash, wash-water rate, duration of wash and amount of wash water. Percentage of wash water, based on previous yield, and hour of backwash should be recorded. Turbidity of applied water and effluents, alkalinities, bacterial tests, chlorine dose and residuals should also be suitably entered. Special notes should be made of any unusual condition, repairs or maintenance work. Routine notes can be written in some self-evident code to facilitate recording.

In a small plant, the generally daily log should show the total hours of filters run, amount of wash water used, and length of time filters were taken out of service for cleaning or repair. Data on turbidities, alkalinities and residual chlorine across the filters likewise are given. A note at the bottom of the sheet should show the wash-water rate and the hours each filter is routinely washed. The amount of wash water is figured for the monthly summary. The form or record sheet should be tailored to fit the needs of each plant individually. A diary to record happenings and information of value not readily tabulated is very desirable.

## CHAPTER 9

# DISINFECTION

**Object.** The object of disinfection is to kill disease producing organisms which may have gained entrance into a water supply. The germs involved are primarily those causing intestinal diseases such as typhoid, the paratyphoids, and dysenteries; most of the other harmful bacteria are not considered to be spread by impure waters because of their short life outside an animal host or an especially favorable culture media. The presence of infantile paralysis virus has been demonstrated in sewage from epidemic areas, although spread of the disease by this means has not been definitely traced. Invariably, in surface waters, are also present typical soil and water organisms regarded as harmless. These types, being well adapted to their environment, may persist for long periods. Sterilization by boiling 15 to 20 minutes is the only certain method for completely killing all living forms, but this procedure is inapplicable except on an individual basis. Other methods, chemical and physical, are effective weapons against disease germs but may still allow reputably harmless bacteria to survive. In water treatment terminology, disinfection refers to the destruction of intestinal or fecal type bacteria.

**Sources of Pollution.** The modes of entry of fecal bacteria into water depend upon the source of supply. Surface supplies, almost universally, receive sewage from dwellings or communities located on the water shed. Protected reservoir areas are subject to contamination by dust, birds, animals and trespassers. Ground waters may carry fecal bacteria when any of the sanitary features, recognized in acceptable well construction, has been violated. Faulty practices, such as use of fissured strata,

location of well site on low ground or near privies, sewers, barnyards, pits or lagoons, leaky casings and surface seals, use of contaminated slush and gravel in well construction, and failure to sterilize properly after completing a well may allow entry of pollution. In the distribution system, contamination may enter through imperfectly sterilized new pipe-lines, repairs to mains and services, cross-connections and back-siphonage.

**Disinfecting Agents.** Methods of disinfection applicable to public water supplies include: (a) chlorination, (b) ozonization, (c) ultra-violet radiation, and (d) overlining. Of restricted importance are potassium permanganate, iodine, and silver. Recently, bromine has been advantageously introduced as a germicide for water supplies. Chlorination is so widely used that the terms disinfection and chlorination are almost synonymous in water works practice. The remainder of this chapter is devoted mainly to this means of disinfection.

Ozonization consists in introducing about one part per million of ozone, produced by passing a high voltage current through air or oxygen, into the water. Its action against bacteria, according to some studies, is rapidly lethal. No material other than air and electric current is required. The U. S. Army is using many portable field ozonizers.

Ultra-violet radiation treatment consists in passing water, which must be clear, in a thin film over a quartz-enclosed mercury vapor lamp. Its sterilizing action is almost complete; no chemicals are required, no odors are formed and there is no possibility of overdosage. Ultra-violet rays provide the best known method for destroying the infantile paralysis virus in infected water. Used alone, its fundamental drawbacks are the large lamp surfaces required to allow flow as a thin film of water and the lack of residual chemical to cope with subsequent pollution. Minerals, if deposited on the lamp, make it ineffective.

Overlining water, usually in connection with softening, is destructive to intestinal bacteria especially above pH 10.3, if

the contact time is longer than about six hours and the water is not too cold. Potassium permanganate and iodine are sometimes used for the emergency disinfection of small batches, as for individuals and small groups. So called "oligodynamic silver" has slow germicidal properties but spares some types of bacteria and its use in portable waters has been demonstrated inadvisable by animal feeding experiments. In bathing pools, the skin of swimmers may be permanently darkened, a condition termed "argyrosis." Bromine acts in a manner similar to chlorine.

**Role of Chlorination.** Ideally, in a water supply, chlorination should function primarily as a safeguard by providing a residual germicide to annul possible pollution in the distribution system. Thus, in a properly working filter plant, chlorination is not truly a part of the purification process, since the coagulation and filtration steps should yield an effluent free from objectionable organisms. If, however, the raw water contains bacteria in such high numbers that occasionally organisms of the intestinal type pass the filters either as a result of lapses in plant efficiency or of excessive raw water pollution, then chlorination is an integral part of the purification process intended to furnish a factor of safety. In such a case, provision should be made against interruptions by installing equipment in duplicate, maintaining reserve chlorine supply, and stocking spare parts for the chlorinator. Tolerable raw water pollution limits when using various types of treatment are as follows:

| <u>Type of Treatment</u>                              | <u>B. Coli Count per 100 ml.</u> |
|---|----------------------------------|
| Chlorination alone                                    | 50                               |
| Filtration and post-chlorination                      | 5,000                            |
| Filtration with prechlorination and post-chlorination | 20,000                           |

When used to disinfect ground waters whose source shows pollution or where exposed to contamination, as in aeration, the

chlorination step is a component part of the plant treatment and is relied on for disinfection.

**Properties and Forms of Chlorine.** Chlorine is a yellowish green gas. It is an extremely active chemical and unites, when moist, with all the common metals, except silver. When present in air in so low a concentration as 3.5 p.p.m., it may be detected by its cucumber-like odor; at concentration above 30 p.p.m. chlorine becomes violently irritating to the membranes lining the respiratory system. During World War I, it was the first poison gas to be used in chemical warfare. As a germicide, chlorine acts upon bacteria through its strong oxidizing effect and its power to attack protein structure. In conjunction with ammonia and ammonium compounds, chlorine forms a series of chloramines which are important as water supply disinfectants.

Chlorine may be purchased in the uncombined state compressed as a liquid into cylinders, or in a loosely combined solid form known as hypochlorite. Liquid chlorine cylinders are commonly available in the following sizes: 100-pound, 150-pound, 1-ton (15 units to a special flat car), and in 16- and 30-ton tank cars. Into a cubic foot of liquid chlorine is compressed nearly 500 cubic feet of the gas. Since liquid chlorine boils at  $-30.1^{\circ}\text{F.}$ , these cylinders at  $70^{\circ}\text{F.}$  are subject to a pressure of 85 pounds per square inch. The seamless steel drums are hydraulically tested to stand 500 pounds per square inch pressure. At the bottom of the valve a fusible safety plug, which softens at  $157\text{--}162^{\circ}\text{F.}$ , prevents explosive bursting by thermal expansion of the liquid. Chlorine cylinders should never be placed near stoves or radiators likely to raise their temperatures near this point. Liquid chlorine is the most economical and convenient form in which to apply chlorine but its regulation requires special equipment.

Hypochlorite is a chemical combination of chlorine with an alkali like lime. Being solid, it is easily transported and administered. Its strength is determined by the per cent of available

chlorine present. The strongest materials (approximately 70% available chlorine, e.g., H. T. H. Perchloron, Hoodchlor, etc.) are true calcium hypochlorites, with sufficient alkali to stabilize them against appreciable loss of chlorine during storage. Ordinary bleaching powder contains from 25 to 35% available chlorine. The remainder is mainly slaked lime. This material loses strength rapidly, once the container has been opened and the contents exposed to the air. True hypochlorites are readily soluble, without appreciable residues, but bleaching powder dissolves with difficulty, and leaves a slurry of slaked lime in the pot. Sodium hypochlorite solutions are obtainable under various trade names but are expensive for water plant use. Hypochlorites are usually fed in solution. Their use is confined to very small water systems, to protection during emergency, and to pipe-line disinfection. In the event of a broken connection, the attendant is not endangered as with liquid chlorine. If either chlorine or hypochlorite are fed on an equal available chlorine basis, practically the same germicidal effect may usually be expected. In completely softened waters, however, the germicidal effect of calcium hypochlorite exceeds that of sodium hypochlorite or chlorine gas.

Two other interesting, but less common, forms of loosely held chlorine deserve mention. Chlorites yield over 100% available chlorine due to the manner in which they react. Some organic chlorine compounds, such as chloramine T, are useful as proprietary sterilizing tablets and offer a wide range in rates of disinfection.

**The Chlorine Residual.** Chlorine reacts so rapidly with most oxidizable material present in natural waters that the amount applied is swiftly depleted. For many disease-producing bacteria, an exposure to as low as 0.2 p.p.m. chlorine for 30 seconds will kill over 99% of those present. This concentration of free chlorine kills all exposed normal intestinal bacteria, the coliform group, within 2 minutes at pH 6 to 7; in about 4

minutes at pH 8; and 6 minutes at pH 9. As an exception, the virus of poliomyelitis is not inactivated by any ordinary dosage. The tularemia organism also requires a somewhat higher chlorine dose.

It is a recognized practice to maintain a control concentration of 0.2 p.p.m. after 10 minutes application to the water. This quantity is known as the *chlorine residual*; it represents the chlorine remaining after the ten-minute reaction interval and still available to combat some of the more resistant organisms and to safeguard against any later pollution. The chlorine actually absorbed is termed the *chlorine demand*; its value is obtained by subtracting the chlorine residual from the original chlorine dosage. The character of the water determines the chlorine demand and the rate of chlorine disappearance; a low mineralized, colorless ground water may show a demand of about 0.05 p.p.m.; a surface water, particularly when high in free ammonia, will consume much greater quantities and retard its killing power. Control of chlorination in each case is aimed to show a minimum residual of 0.2 p.p.m. free chlorine, para-aminodimethylaniline method or an equivalent procedure preferred, when tested ten minutes after dosing. Chlorinator or hypochlorite feed equipment is adjusted on this basis. An increase in the residual should be carried if ammonia is present or if bacteriological findings warrant.

The details of the residual test are given in Chapter 19. As ordinarily employed, the procedure is to add a small volume of orthotolidin solution to the water sample. Any residual chlorine produces a yellow coloration which is compared against standard colors to determine its concentration. For residuals above 1.0 p.p.m. chlorine, a slightly longer test, the starch iodide method is preferable, but the orthotolidin test is applicable if the water sample is diluted. The recently developed para-aminodimethylaniline test for free chlorine, unaffected by the chlorine-ammonia compounds, and the orthotolidin-arsenite test



to eliminate false residuals are also described. An electrical method, based on so called oxidation-reduction potential is being used with gratifying success in a few plants.

**Care of Cylinders.** Chlorine can be vaporized from 150-pound cylinders at the rate of 35 pounds per 24 hours. Where greater rates of feed are required, a suitable number of containers should be manifolded, otherwise freezing of the chlorine will be caused by the chilling effect of evaporation. Cylinders should be placed on a scale so that a check may be made on the daily withdrawals for comparison against the scale setting, and also to show when a tank has been emptied. For convenience, the scale platform should be set flush with the floor. Cylinders should be strapped in position to prevent overturning. Tank pressure is no index to the amount of chlorine remaining in a cylinder as the pressure depends solely upon the temperature so long as any liquid is left. Cylinders should be kept cooler than the temperature of the chlorinator, otherwise condensate will form in the transfer line or in the feed apparatus. If a space heater is used to warm the chlorinator, an insulating shield should screen off the cylinders. Temperature surrounding chlorine drums should range between 50° to 85°F. A taffy-like gum, consisting mainly of hexachlorethane, is present in small amounts floating on the liquid chlorine surface. To prevent plugging screens and orifices, this material should be removed by blowing off about two pounds of chlorine to the atmosphere, outside of the building, before connecting a fresh cylinder to the feed apparatus.

Handling of cylinders is facilitated by using dollies for small sizes and cranes or trucks for ton containers. Lifting is done in some sort of supporting cradle; never by passing a cable through the cap slots. Cylinders should stand upright in a well ventilated room. Construction of the chlorinator room should be safe and fireproof so there is no danger of flames igniting the rubber delivery tubing and other connections. An acid-resistant exhaust fan, with exterior switch, should be installed

near the floor level whenever natural draft is insufficient, as when storing chlorine in cellars or rooms with high openings. The protective hood should not be removed until the cylinder is connected for service. To connect, the delivery tubing may be screwed to the cylinder outlet as a half union, using an asbestos or lead gasket or, more desirably, connected by a special clamp furnished gratis by the manufacturer. Never use a rubber or soft lead gasket. See Figure 19. To ensure that no condensate will trap the flow of gas, the delivery line should

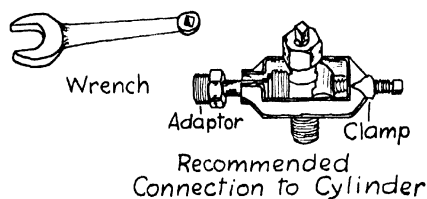
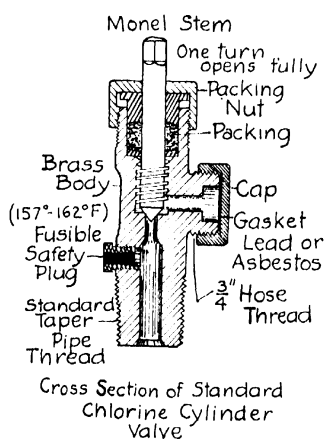


FIGURE 19

Chlorine Cylinder Valve, Wrench, Adaptor and Clamp

be run without pockets or sag, if a low temperature span is crossed. Oversize wrenches should never be used; a spanner, furnished with the equipment is best employed in making connections and opening the valve. If the stem is frozen, it may be freed by loosening the packing nut one turn, tapping the end of the stem and knocking the valve wrench sharply by hand. Similarly, tightening the packing nut will check leaks about the stem. *The safety plug should never be disturbed.* When the cylinder is empty, the valve should be closed, so that it becomes impossible to draw water back into the cylinder by suction and thus dangerously corrode the container.

**Chlorine Leaks and Safety Measures.** All chlorine leaks should be located and remedied if possible, as they become worse with age, discomforting operators, corroding metal equipment nearby and possibly endangering attendants. A safety chart may be obtained from chlorine dealers and hung near the chlorinator.

A separate gas mask, approved for chlorine protection, should be placed at a safe distance *outside* the chlorine room for as many men as may be exposed at one time. Cannister masks are unsafe when chlorine concentration exceeds 1% or when oxygen drops below 16%. In such cases oxygen breathing apparatus is needed. A bad mask obviously is worse than useless.

Leaks are located by passing an open ammonia water bottle in the vicinity of the suspected leak. When the leak is severe, a rag soaked in this material should be used as a long-handled swab. Dense white fumes of ammonium chloride will indicate the location of the leak. If the leak is in the delivery tube or chlorinator, shut the cylinder (valve closes clockwise), ventilate room until the chlorine is removed, then make the repair if possible. When the leak is at the valve stem, it may be stopped by tightening (clockwise) the packing nut.

If the cylinder leak is uncontrollable, the container should be moved out of doors to a point where least damage is liable to

result from escape of chlorine. Escape of liquid should be prevented by standing the cylinder upright. Chlorine may be absorbed in a slurry made with 10 pounds of hydrated lime in 10 gallons of water;  $1\frac{1}{2}$  pounds of lime is needed for each pound of chlorine to be absorbed. An absorbent solution may also be prepared by dissolving three pounds of soda ash or  $1\frac{1}{4}$  pounds of caustic soda in a gallon of water for each pound of chlorine to be disposed. Rapid withdrawal of chlorine, prior to moving the cylinder, chills the liquid and reduces the vapor pressure, thus retarding the rate of leakage. Pressure inside the cylinder may also be reduced by a jacket of dry ice. Spraying water over a chlorine leak merely makes conditions worse because of corrosion. Effective disposal is possible by submerging the cylinder under a large volume of *cold* water or in a moving stream, below 49.2°F., in which chlorine gas readily dissolves.

**Operator Safety.** A 30-minute exposure to over 40 p.p.m. of chlorine in air, according to the U. S. Bureau of Mines, is dangerous to humans. Irritation of the respiratory mucous membranes and symptoms of a hard cold result from its inhalation. In fatalities, death is usually from suffocation, as the victim becomes unable to breathe and the bronchial tubes shut spasmodically. Recovery from mild exposure is complete; should exposure be severe, recovery is expected if the victim survives for 30 minutes. Persons with asthma and bronchitis should avoid exposure.

### EMERGENCY PRECAUTIONS

1. Hold head high, as the chlorine concentration is greatest at floor level.
2. Keep mouth closed.
3. Avoid deep breathing and gasps caused by coughs.
4. Seek safety.

### *FIRST AID PROCEDURE*

1. Remove victim to fresh atmosphere, preferably a room near 70°F. Warmth and rest are essential.
2. Lay patient on back with head and chest elevated.
3. Summon a physician immediately.
4. Remove parts of clothing wet with liquid chlorine or heavily chlorinated water to avoid acid burns or irritation. Be sure to keep patient warm with cover.
5. Administer a carbon dioxide-oxygen mixture, not exceeding 7% carbon dioxide, intermittently for two-minute periods, separated by two-minute rests for half an hour.
6. In mild cases, milk will relieve discomforting throat irritation. A moderate stimulant, such as black coffee or a half-teaspoonful of essence of peppermint diluted in one half a glass of warm water, relieves the impulse to cough and promotes respiration. Do not administer alcoholic drinks. Breathing in vapors of warmed methol salve or tincture of benzoin comforts the nasal passages.
7. If breathing has stopped, apply artificial respiration using the prone pressure method at no faster than an 18-movement per minute rate.

### CHLORINATORS

Apparatus for applying gaseous chlorine to water falls into two broad classes: dry feed and solution feed. Dry feed machines are useful at points not served by a pressure water supply; in cases where the type of feed is open to choice, the solution feed chlorinator is generally preferable.

**Dry Feed.** In a dry feeder, cylinder pressure is used and chlorine passes through a spring-actuated reducing valve directly to some sort of diffusion tip placed in a conduit or in a main. With some types, back-pressure may be as high as 25 psi. The chlorinator, Figure 20, consists essentially of a reducing

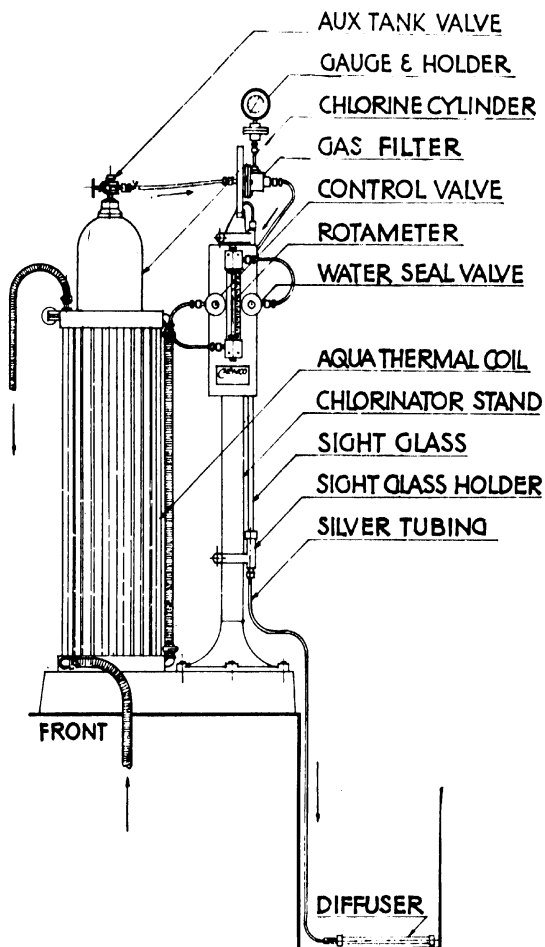


FIGURE 20

Dry Feed Chlorinator, Type TR

(Courtesy of Chemical Equipment Co. of California, Los Angeles, Calif.)

valve and a rate of flow indicator, such as a rotameter or a U-tube manometer connected across an orifice in the low pressure chlorine line. Fluctuations in gas pressure due to temperature variations of the liquid chlorine are minimized by enclosing the cylinder within a vertical nest of coils through which pass tap water. This coil is useful also with solution feed machines, in which case the water is used for the injector. If the gas is applied in an open flume, the diffuser should be submerged at least four feet, preferably six feet. For use with cold water, a heated injector tip prevents the formation of chlorine ice.

A chlorine cylinder without equipment may be used for direct feed during an emergency, controlling the rate by counting the bubbles per minute through a water trap. Low sensitivity of the cylinder valve limits the adjustment to about one half pound per hour.

**Solution Feed.** Solution feed chlorinators apply chlorine after first dissolving the gas in injection water. A compensating valve provides a constant chlorine pressure regardless of fluctuations in the cylinder caused by outside temperature changes and chilling effects of withdrawals. Solution may take place directly in the injector unit, which is a Venturi aspirator, by sucking gas from the metering device or solution may occur in a short gas absorption tower before entering the ejector suction. To apply this chlorine solution against pressure requires an injection water pressure usually three times greater than that at the point of application.

Gas may be metered under pressure or vacuum. Chlorine tank pressure is reduced by a diaphragm regulator placed ahead of the chlorinator. Machines that meter under pressure employ an orifice or a water displacement trap. In the latter case, the rate of flow is indicated by the number of gulps or bubbles of chlorine passed in a given time interval. Chlorinators that meter under a slight vacuum may also use these methods. In such apparatus, small leaks tend to draw in air, rather than

allow escape of chlorine. In Figure 21 is shown the flow diagram for a chlorinator that measures the rate of flow by the loss of head across an orifice; control of flow is obtained by regulating the amount of vacuum transmitted from the injector suction through a variable depth water seal. A pulsation type meter is employed in the chlorinator illustrated in Figure 22. Another widely used metering device is the rotameter, a tapered glass tube containing a light tantalum float, whose position in the rising gas stream is determined by the rate of flow, as indicated in Figure 23.

Automatic stop and start may be achieved by interrupting the injector water or by closing a hydraulic valve in the chlorine line in synchronism with water flow from the station. More elaborate equipment is available to regulate chlorine feed automatically with rate of water flow through the plant for those cases where pumpage fluctuates. Automatic proportioning to furnish a desired constant residual with a variable chlorine demand is a recent development.

**Principles of Operation.** Closer descriptive details of the three illustrated types of manually controlled chlorinators which meter the gas under a slight vacuum are presented below:

*Orifice Meter Type (See Figure 21).* The main flow of water enters the machine through a strainer and flows through the injector to the point of application of the chlorine. The water flowing through the injector creates a suction which is transmitted to the adjustable suction tube. The adjustable suction tube pulls gas through the orifice meter and make-up water from the hard-rubber, constant-level box mounted in the rear of the machine. The water to this constant-level box is supplied through and controlled by the float-operated make-up water valve. This water is supplied from the auxiliary water system. The height to which this make-up water must be pulled to reach the top of the adjustable suction tube determines the amount of vacuum produced in the orifice meter. Turning the control knob on the front of the machine raises or lowers



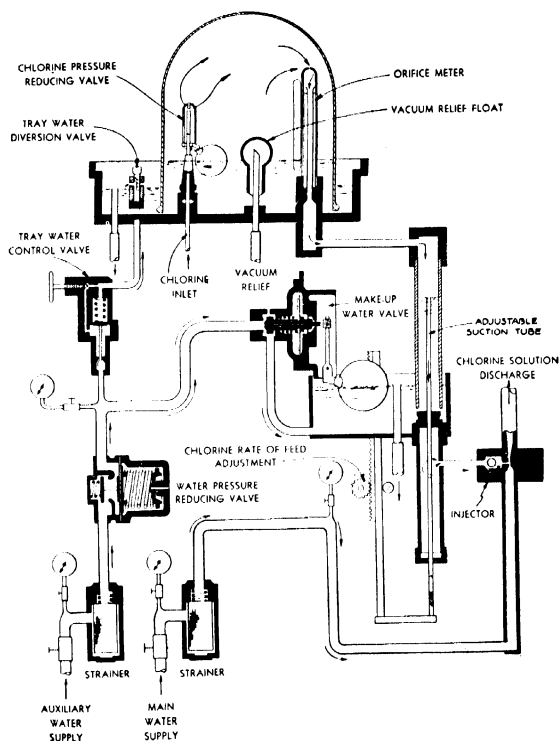


FIGURE 21

Flow Diagram of a Solution Feed Chlorinator with Orifice Meter,  
Type MSV

(Courtesy of Wallace & Tiernan, Newark, N. J.)

the rack which carries the injector suction tube. This adjustable vacuum determines the rate of feed of the chlorinator. The rate of feed is indicated by the height of the water column appearing in the orifice meter. The amount of chlorine being fed is indicated by the scale which is attached to the outside of the meter.

The chlorine is admitted to the bell jar by means of the chlorine pressure reducing valve. This valve maintains the rate of flow equal to the amount passing through the orifice meter. In this way, the water level inside the bell jar remains is allowed to enter the large section of the tray in order to use in the tray is supplied through a control valve from the auxiliary water system. A diversion valve is provided in the tray itself to enable the tray water to be split into the large and the small compartments. It should be adjusted so that most of the water flows into the small compartment. A small flow is allowed to enter the large section of the tray in order to prevent the tray water from becoming too rich in chlorine with resultant fuming.

When the chlorinator is out of operation or when the cylinder of chlorine becomes empty, it is natural for a vacuum to be created which will draw water up into the bell jar. It is not desirable for water to rise in the bell jar more than an inch above the normal operating level. For this reason a vacuum-relief float is provided which will admit air to the bell jar when this water level rises above normal. This device has a further function of discharging excess chlorine to outside the building if conditions were such that a pressure of chlorine was built up under the bell jar.

*Pulsation Meter Type (See Figure 22).* Straight arrows show the path of chlorine flow. Chlorine enters the machine at the compensator inlet, flows through the meter chamber, passes over to the injector suction chamber and is drawn into the injector tube throat. There, the chlorine is mixed with water and carried in solution to the point of application.

The compensator, a type of regulator, maintains a constant flow of gas for any given setting of the control valve by which the rate of feed is adjusted. By counting the number of pulsations per minute under the meter bell the rate of flow may be determined from a chart. By sucking seal water, the water seal at the bottom of the chlorine outlet from the injector

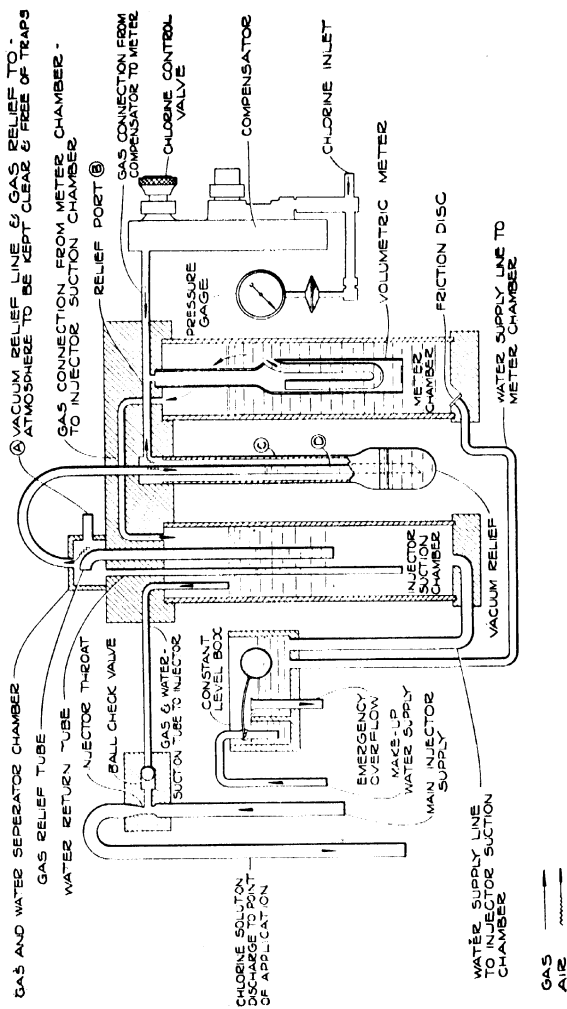


FIGURE 22  
Flow Diagram of a Solution Feed Chlorinator with Pulsation Meter, Type MSP

(Courtesy of Wallace & Tiernan, Newark, N. J.)

suction chamber maintains a slight vacuum equal to the difference between water levels in the injector suction chamber and the constant level box.

The vacuum relief bulb prevents water from being drawn back into the compensator. The gas relief tube prevents gas pressure from building up sufficiently to escape through the constant level box.

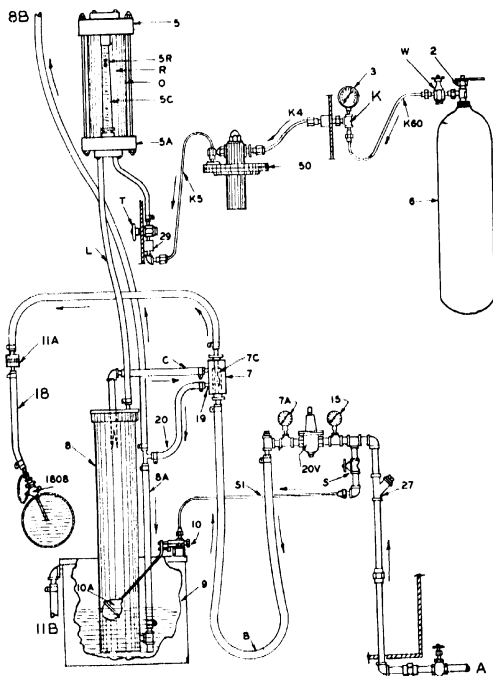


FIGURE 23

Flow Diagram of a Solution Feed Chlorinator with Rotameter,  
Series 1900 Type F

(Courtesy of Everson Manufacturing Company, Chicago, Ill.)

*Rotameter Type (See Figure 23).* Water under a reduced pressure, obtained by means of regulator (20V), flows through injector (7) which induces a vacuum in the gas absorption tower (8). This vacuum lifts water from the constant level reservoir (9) through the tower to absorb the chlorine and pass through the solution line (C) to the injector; thence to the point of application at the corporation cock (1808).

Chlorine passes through the vacuum gas regulator and shut-off (50), the needle type control valve (T), the rotameter tube (5C) and through the gas outlet line (L) into the gas absorption tower, where mixture and discharge with water occurs.

The vacuum gas regulator and shut-off (50) automatically stops the chlorine flow, should the water pressure fail; it opens again when pressure is restored. This action is obtained by means of a weight loaded diaphragm which closes a small port if the vacuum in gas line (K5) above the diaphragm falls below approximately 20 inches (water gage).

In the rotameter the chlorine flow raises a spinning top, rotor (5R) in the upwardly tapered tube (5C); the position of the rotor is read on a scale divided directly in pounds of chlorine per day.

Gas vent line (8B) permits any free gas in the absorption tower and tubing to escape to the outside if water pressure fails. If the chlorine lines break, their vacuum is destroyed and the vacuum gas regulator and shut-off stops the flow of chlorine from the cylinder. Safety syphon break line (20) prevents back syphonage from the machine into the main water supply. Check valve (11A) is an optional item.

**Operating Steps.** The essential point to observe in starting a solution feed chlorinator is that the water valves are opened first and then the chlorine valves. On closing, the reverse order is followed. Functions of some of the valves vary with the make of equipment, but most chlorinators are sufficiently similar for the following general steps to apply:

1. Ascertain that the delivery hose to the point of application

is clear. If injected into a main, insert the silver solution tube through the corporation cock connection.

2. Turn on the water supply to the injector and other water connections. Adjust pressures at gages.

3. Open chlorine cylinder valve about one-half turn, then auxiliary gas valve about one and one-half turns.

4. Regulate chlorination control valve slowly until desired chlorination feed is indicated on the meter.

Daily routine includes a search for chlorine leaks with an ammonia water tracer, noting water gage reading and adjusting if needed, weighting cylinders, replacing empties, and maintaining cleanliness in the chlorination booth. At least several times a day a residual test should be made on the treated water and the feed adjusted if required.

To shut off chlorination the above general steps are reversed:

1. Close the cylinder valve and the auxiliary tank valve.

2. When the chlorine gage has dropped to zero and the machine has been flushed out by the air relief, close down the water supply valves.

3. Remove solution tube if application is in a main and close the corporation cock. Do not crush the silver tube by closing the corporation cock before withdrawing the tube.

**Trouble Shooting.** Failure of a machine to deliver the desired flow of chlorine may be due to conditions in the cylinders or in the chlorinator. Whenever the chlorinator is dissembled, metal parts that had been in contact with chlorine should always be cleaned off with carbon tetrachloride (sold under the name of Carbona) to remove last traces of chlorine gas before atmospheric moisture can start corrosion. Methyl alcohol and chloroform may likewise be used as cleaning agents. Tubes and ports may be cleaned out by pouring through a few ounces of carbon tetrachloride; persistent deposits may be dislodged after several hours soaking. Carefully poking through openings by means of a fine wire cleans passageways. Rubber fittings should be screwed up hand tight only. The threads may be lubricated by

preparations like Dixon's Graphitoleo No. 692. In a vacuum type machine, the bell jar, if any, should be kept clean with powdered soap cleaner; the stuffing boxes should be tight enough to prevent leakage but should not work with difficulty. Screens in water lines should be cleaned whenever pressures cannot be held at proper values. Exposed metal parts on the chlorinator and scales should be kept covered with petrolatum or a similar protective coating to reduce corrosion caused by occasional leakage of chlorine.

Where the manufacturer's manual of instructions specifies factory repairs for certain failures, its directions should be followed. Some typical troubles are enumerated below:

1. *Frozen Chlorine Line.* This is caused by withdrawal of gas from the cylinder too rapidly. The remedy is to place more cylinders in service or to provide a heater on the chlorine line. Cylinder temperature should be maintained between 50° to 85°F.; lower temperatures cause weak pressure whereas higher temperatures may distil over liquid condensate.

2. *Failure of Chlorine Gage to Show Pressure.* The diaphragm is probably punctured. Be certain to clean out pressure transmission oil that has leaked into the chlorine lines.

3. *Frozen Chlorine on Float Regulator Valve.* Considerable expansion at this point causes occasional freezing. At low temperatures, chlorine unites with water to form solid chlorine hydrate. Remedies include: (a) the use of a space heater in the chlorinator room or an electric light bulb near the bell jar; (b) heating the chlorine line by an electric heater, and (c) heating the tray water either by warming the water supply to the tray or jetting in water at 70°F. under the bell jar.

4. *High Water Level in Tray.* (Standing above Scale Zero when no Chlorine is Discharging.) A clogged chlorine feed line is usually indicated. More rarely the scale zero needs resetting by lowering the float valve carriage by the screw underneath the tray.

5. *Low Water Level in Tray.* Poor injector suction is indi-

cated. Water pressure should be checked; impaired flow may result from sand or scale clogged or rusted strainer. The injector may clog on the raw-water side, or the parts may have worn. In this case replacement is needed.

## HYPOCHLORINATORS

Devices for the application of hypochlorite solution against pressure are of two types: a pressure pot connected across an orifice in the water main, and a small reciprocating pump.

**Pump-Type Hypochlorinators.** Reciprocating pump-type hypochlorinators are applicable to water supplies ranging from 100 to 100,000 gal. per day consumption. Injection pressures may reach 100 psi. Pistons are driven through a speed reducer from a low- or fly-power motor or by a water meter in the main. In the latter case, the pump discharges in proportion to the rate of flow. Motor driven pumps may be made semi-automatic; that is, starting and stopping in step with a high lift pump or the like, by means of a water pressure switch or a transformer connected on the cold side of the pump motor switch. Piston motion of the hypochlorinator may be varied by the throw of a crank or eccentric drive. Further range of delivery rate is obtainable by a choice of speed reductions and by varying the strength of the hypochlorite solution. Pumps are usually of the rubber diaphragm type pulsating in a rubber, glass or plastic chamber. When making up solutions with hard water, preliminary softening and separating from the precipitate will reduce the amount of sludge formed by the hypochlorite powder. Introducing the solution into a hard water supply causes a scale to form inside the silver injection tube unless make-up water is softened or calgon is added to the solution crock (about 10 p.p.m. or more) to inhibit precipitation.

**Constant Level Type.** For feeding into an open channel, an orifice tank, having a float valve to maintain a constant solution level, is satisfactory. By separately feeding seal water to supply



sufficient volume, this simple device is also applicable directly connected into pump suction; when aided by an injector, it works against slight pressures. Such an arrangement is shown in Figure 24. The upper crock is used to dissolve the powder,

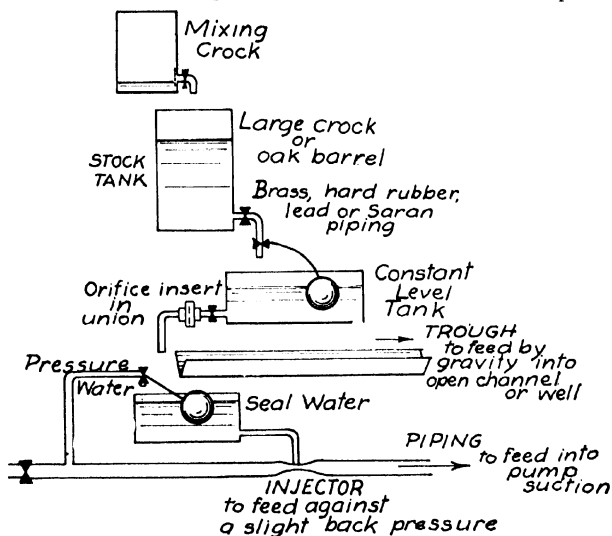


FIGURE 24

#### Hypochlorite Solution Feed, Float Tank System

and after settling the insolubles, the clear supernatant is run into the stock barrel where dilution water is added to reduce the concentration as desired. Uniformity of feed is maintained by the constant level box, which may be a toilet flush tank, emptying through an orifice in the bottom. The orifice may be made by inserting a corrosion-resisting disc, having a hole reamed to proper size, inside a union.

**High Level Tank.** For maximum simplicity, the hypochlorite solution may be made up and fed with sufficient uniformity without constant level control provided the barrel is

mounted a substantial height, about 10 feet, above the orifice discharge, as illustrated in Figure 25. If the variation of the

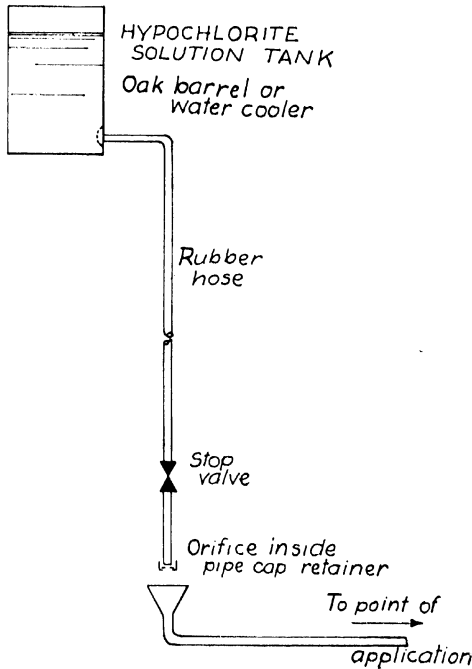


FIGURE 25

Simple Hypochlorinator Feeding at Nearly Constant Rate by Means of a High Tank

operating level in the barrel is restricted to 2 feet, this elevation provides uniform dosage, within 5% of the average. The orifice is merely a perforated pipe cap into which a series of liners, having various diameter openings, may be inserted to vary the rate of feed. Control may also be had by means of the stop valve. Adjustment of feed is also obtained by varying the

position of the orifice, however, the uniformity of rate suffers if the orifice level is too high. This arrangement is quickly adaptable to emergency conditions as it entails a minimum of detail. Other solution feed equipment as described in Chapter 7 is adaptable for use with hypochlorites. Rate of solution flow should be checked daily by noting the drop per hour in the solution tank or by timing the interval to catch a small volume like a pint bottle. A residual chlorine test should be made on the treated water frequently and adjustment in rate of feed made accordingly.

**Hypochlorite Solution Calculations.** The quantity of hypochlorite solution to prepare at one time should be sufficient to last for about two weeks. A common strength is 1% available chlorine; this means that every gallon or 8.34 lb. will contain 0.0834 lb. or 1.34 oz. of active chlorine. If bleaching powder, 33% available chlorine, is used each gallon of stock solution should contain  $\frac{1.34}{0.33}$  or 4.06 oz. When HTH or Perchloron, with 70% available chlorine, is employed each gallon of 1% solution will contain  $\frac{1.34}{0.70}$  or 1.92 oz. of material. Bleaching powder solutions of this concentration lose only about 1½% per week in strength, if stored in the dark. The loss rises to nearly 3½% in daylight. Nickel containers should be avoided because this metal accelerates the breakdown of hypochlorites.

Greater stability, lasting over a month, is gained if soda ash is added to transform the solution to sodium hypochlorite. HTH-15 contains soda ash in proper proportion to form sodium hypochlorite. HTH or Perchloron require 3 lb. of soda ash for every 4 lb. of chemical; ordinary bleaching powders require about half as much soda ash. The calcium carbonate sludge formed as a reaction product should be allowed to settle to the bottom of the vessel and the clear, stable supernatant liquor syphoned off for use.

The amount in gallons of 1% available chlorine solution required to dose various volumes of water at the rate of 1 p.p.m. is obtained simply by dividing the water gallons by 10,000. The ounces of hypochlorite required to chlorinate water at a 1 p.p.m. dosage is given in the chart, Figure 26. For any other dosage the figure obtained from the chart is multiplied by the dosage desired. The gallons of water to prepare a 1% solution using this quantity of hypochlorite is found by dividing the weight in ounces by 1.92 in the case of NTH and Perchloron, and by 4.06 for ordinary 33% bleaching powders. The volume of stock solution naturally is the same in either case, as the strength is constant.

Application rate of hypochlorite solution should be based on actual pumpage in gallons per minute and not on the average over-all 24-hour consumption. The volume of 1% chlorine solution needed per minute to furnish a 1 p.p.m. chlorine dosage when injected into a pipe-line flowing 1,000 g.p.m. is simply 1,000/10,000 or 0.1 g.p.m. Since a gallon contains 3,785 milliliters (ml.) this hypochlorite stock solution feed is equal to 378 ml. per minute. In general for any desired dosage and pumpage rate, when using 1% chlorine solution, the rate of injection is given by the formula:

$$\text{Hypochlorite solution (ml./min.)} = \frac{378 \times \text{dosage (p.p.m.)}}{\text{flow (g.p.m.)}}$$

Inversely, to check the chlorine dosage, catch the discharge from the hypochlorinator in a graduate cylinder. If a 1% available chlorine solution is used the chlorine dosage (p.p.m.) is calculated from the formula:

$$\text{Chlorine dosage (p.p.m.)} = \frac{\text{Hypochlorite solution (ml./min.)}}{378 \times \text{pumpage (g.p.m.)}}$$

If another strength of chlorine solution than 1% available chlorine is considered, these formulas are modified accordingly. Thus for a 0.5% solution results in the first formula are divided by 0.5, while those in the last formula are multiplied by 0.5.

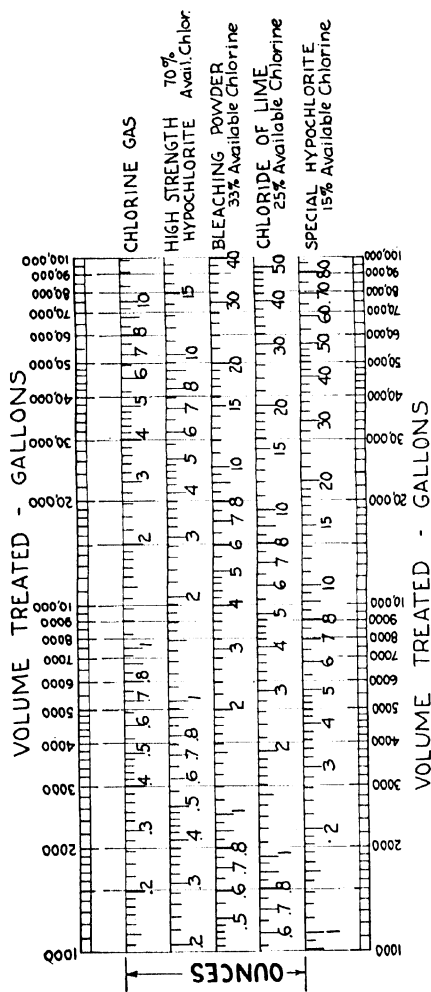


FIGURE 26

### Chlorine Dosing Chart

Ounces of chlorine or various hypochlorites required to treat various volumes of water at a 1 p.p.m. chlorine rate.

(Courtesy of *Water Works Engineering*)

## TYPES OF CHLORINATION

**Versatility.** Aside from its use as a germicide, chlorine has also the following important applications in a water plant: (a) algacide, (b) taste and odor control, (c) iron and manganese removal, (d) coagulation aid, (e) preparation of chlorinated copperas and of chlorinated clay, (f) emergency disinfection, (g) pipe-line disinfection, and (h) destruction of pipe-line organisms. Hence the technique of chlorination is influenced by the other accompanying functions in addition to that of disinfection. According to the manner and point of application, procedures have been classified as: (a) simple chlorination or post-chlorination, (b) prechlorination, (c) superchlorination, (d) break-point chlorination, and (e) chloramination. Frequently chlorine is applied at two or more points in the treatment.

**Post-Chlorination.** Post-chlorination, the simplest method of application, consists of feeding chlorine after filtration. Its main object is to provide a chlorine residual to operate as a factor of safety in the distribution system and occasionally to reinforce the filtration process by killing some organisms that may have persisted through the plant. Dosages may vary from 2.5 lb. per million gallons to over 8 lb. per million gallons, depending upon the hardness, amount of organic matter present, and the distance in the system where a residual is desired and its amount. The upper limit of dosage is the taste and odor threshold for excess chlorine and for chlorinous tastes and odors formed by reaction with organic materials present. High sodium alkalinity tends to permit large dosages without incurring chlorine tastes. Untreated well supplies which are aerated receive simple chlorination; many well waters which are used directly without other treatment are chlorinated for a margin of safety or to control organisms that grow in pipe-lines. A reaction time of at least 20 minutes should be allowed before the water reaches the first consumer.

**Prechlorination.** Prechlorination denotes addition of chlorine at any point in the plant prior to filtration, and in amounts that do not produce an unusual residual. The doses usually exceed those employed in post-chlorination. Applied to the raw water, some types of algae may be controlled and organic material oxidized, thus aiding coagulation. Where employed mainly to keep the filter beds clean from algae, application to the settled water is generally more economical than to the raw water. The bacterial loads on the filter are reduced. Prechlorination of a well supply is useful in retarding algae growths on an unhooded aerator, in oxidizing iron and in combining with any small amount of hydrogen sulfide present.

**Superchlorination.** Superchlorination implies heavy dosage, always before filtration, to furnish so high a residual that some of the excess must be destroyed by standing, by addition of ammonia, or by a dechlorinating agent. This procedure is useful mainly to destroy by oxidation certain types of tastes and odors such as from phenols, and the reduction of susceptible algae. Other benefits accrue incidentally, such as enhancement of coagulation, and increased sterilization rate. Dechlorinating agents include: activated carbon, sodium thiosulfate, and sulfur dioxide.

**Break-Point Chlorination.** Break-point chlorination involves the addition of at least a sufficient amount of chlorine to produce a minimum residual after first satisfying the chlorine demand. This definition may be clarified by reference to Figure 27, which shows the changes in the residual effected by increasing dosages. If the water had no chlorine demand, the residual should equal the dosage and the straight line, marked theoretical residual, would apply. Actually, however, a small dosage which must be added before there is a show of residual (this dosage, represented by the gap at the origin of the chart) is termed the initial demand. Once this initial demand is satisfied, if present, further addition of chlorine will build up the residual correspondingly, unless organic material

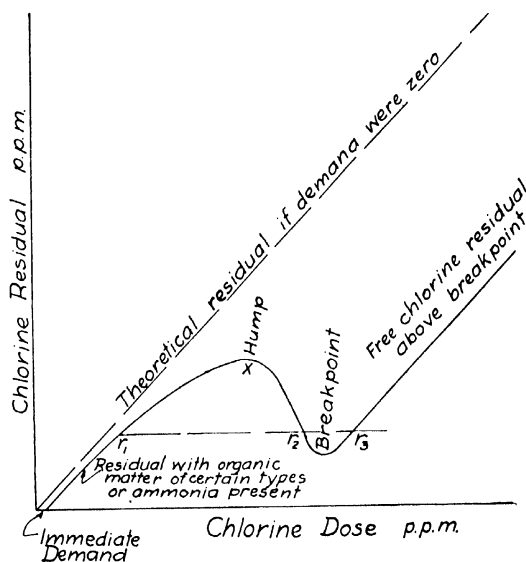


FIGURE 27

## Dosage-Residual Relationship in Break-Point Chlorination

or ammonium compounds are present. In such case the rate at which the residual rises with increasing chlorine feed is progressively less than expected, the dosage-residual curve slumps over to the right as shown, and after reaching a maximum, as at point X, the residual drops suddenly and decidedly, even though the dosage is increased slightly further. Continued chlorination decreases the residual finally to a minimum value, after which the residual will rise in step with chlorine feed.

This minimum is termed the break-point because of its prominence in the curve and the changed character in the taste and appearance of the water. *Break-point* chlorination consists in feeding sufficient chlorine to exceed the break-point; when smaller quantities are used the treatment is termed *marginal*



chlorination. Many tastes, odors, and colors resulting from algae, domestic pollution, and industrial waste, including phenols, are completely destroyed when chlorine is fed in break-point quantity. If chlorine is added below the dosage at the hump X, the objectionable quality may be aggravated; from this hump on to the break-point, the taste or odor will lessen; beyond the break-point, only the odor of excess chlorine is apparent, and this may be eliminated by sufficient retention period, aeration, addition of ammonia, activated carbon, or some of the usual dechlorinating agents, most commonly sulfur dioxide. Not all waters, even though tastes are present, show the typical features of the break-point curve, but even in many of these non-typical instances, superchlorination will be decidedly beneficial. Most supplies of this type may be made to exhibit an induced break-point by adding ammonia prior to chlorination.

Highly polluted waters may display a series of multiple break-points, before the organic material is completely oxidized. Lining generally interferes with break-point reactions; the optimum pH range lies between 6.5 and 7.5 depending on the dissolved solids. Other treatment reduces the chlorine dose needed and sharpens the characteristics of the break-point curve by coagulating out the more complex organic compounds. Iron and manganese are oxidized incidentally by this treatment. However, some tastes resist improvement even when a characteristic break-point is exceeded, requiring activated carbon as an adjunct. When only a slight excess of chlorine content remains after the break-point, its characteristic taste is much milder than the magnitude of the residual suggests. A contact time of three hours, subject to individual determination, should be provided to allow completion of the break-point reactions.

From the standpoint of disinfection, bacteria are much more rapidly killed beyond the break-point than by ordinary chlorination. Some plants, bothered by persistent primary gas formers thought to be of no sanitary significance when testing for bac-

teria, have eliminated these organisms only after adopting break-point chlorination, usually for a taste problem. Removal of biological growths from pipe-lines is credited also, by some authors, to the destructive action of free chlorine on food materials and growth promoting factors. In many cases, residuals beyond the break-point are quite stable.

*Break-point Recognition.* A question always confronting the operator using this treatment, is to interpret a given value of the residual with reference to the break-point. Thus in Figure 27 the residuals  $r_1$ ,  $r_2$  and  $r_3$  are all equal in amount, but are located on different portions of the curve, and hence each has a different significance. Only at the point  $r_3$  has sufficient chlorine been added to exceed the break-point. Fortunately, the orthotolidin test indicates qualitatively the relation of a residual to the break-point as well as its numerical value. When chlorinating beyond the break-point, the yellow color formation flashes immediately as contrasted with its slower development below break-point dosage. A common control in break-point application consists in maintaining the instantly formed orthotolidin residual to exceed at least 85% of the color match reached after 5 minutes standing. Some operators prefer that the instantly formed residual matches the 5 minute residual almost 100%. At least several minutes' contact between the point of chlorination and the sampling station must be allowed to avoid a false flash.

Orthotolidin hydrochloride without acid, using 2 drops of indicator solution per 100 ml. water sample, or ordinary orthotolidin prepared with only 1/7.5 the usual amount of acid does not show color below the break-point but forms instantly a blue or yellow color, depending on pH, slightly beyond the break-point. In many cases, the color, taste or odor of the water sample itself will reflect whether the break-point has been reached. Other characteristics which may serve to recognize break-point attainment are: the coloration of para-aminodimethylaniline, the rapid fading of methyl orange-xylene cyanole

indicator, the absence of free ammonia, the rapid reaction with nitrites, and the equality of acid and alkaline titrations of the water with sodium thiosulfate. Also using sodium arsenite to titrate chlorinated water surrounding an electrical indicator, termed an amperometer, the break-point may be studied.

Directions for a jar test study of a water supply to determine possible improvement by break-point chlorination are given in Chapter 19.

**Ammonia-Chlorine Treatment.** Chloramination is the joint application of some form of ammonia with chlorine. The source of ammonia may be liquid ammonia, in 100-pound steel cylinders fed through an ammoniator analogous to a dry feed chlorinator; aqua ammonia, that is ammonia water; or an ammonium salt, generally ammonium sulfate which may be fed through a dry feeder or in solution. A widely used ratio is four parts of chlorine to every one part of ammonia. The ammonia is usually applied just prior to chlorination, at some point where a complete mix is assured. The combination products of chlorine and ammonia are termed chloramines; a series of these compounds may be formed, the particular members present depending on the pH of the water. Below pH 7 and at low temperatures, the chloramine formation is sluggish; this leaves some free chlorine in the water for a time with resultant rapidity in disinfection. As germicides, chloramines act slowly on organisms; for the same rate of kill twenty to thirty times the free chlorine concentration is required. Chloramines possess the valuable advantage of greater stability over plain chlorine in solution.

Whereas chlorine residuals, especially below the break point, ordinarily dissipate rapidly on standing and in most distribution systems disappear completely after a certain distance from the plant, a chloramine residual is more persistent and cases are known for it to take over a week to vanish from a water sample. In the mains a chloramine residual may retain almost its original value far out to the end of the system. In this way chloramines

provide a factor of sanitary safety exceeding that of chlorine out to the dead ends. However, because of the slower action of chloramines on bacteria, a residual no less than double the usual value carried with chlorine should be maintained. At least two hours' contact period with the water should be allowed before delivery to the first consumer in those cases where filter performance must be supplemented by disinfection. Particularly above pH 8 is the killing effect sluggish.

Persistency of residuals makes chloramine treatment effective against many aftergrowths in the distribution system, and successfully combats corrosion caused by iron-consuming bacteria. Chloramine residuals may be considerably higher than simple chlorine residuals before taste from excess dosage is noticeable, and when detected, the chloramine tastes and odors are not nearly so pungent as those caused by chlorine. Chloramine treatment is also useful in taste control with waters containing phenol and like pollution, in which case chlorine is prevented from forming chlorphenol tastes and odors. Thus, addition of ammonia to a chlorinated supply may be made both to mask taste and stabilize the residual. A few waters contain sufficient ammonia to give a slight chloramine effect naturally. In performing residual tests, the orthotolidin method is used at 20°C. as with chlorination, however, by supplementary tests described in Chapter 19, chloramine residuals may be distinguished from those of chlorine.

**Pipe-Line Disinfection.** All newly laid or repaired mains should be chlorinated to protect the consumers against the inevitable pollution sustained during transit, delivery, storage, and laying. This safeguard is particularly necessary when using second hand pipe or old lines previously used for other purposes. Often pipe must be placed in soggy trenches and in contact with sewage admitted through frequent service cuts. To ensure successful disinfection, the pipe-line must be mechanically clean before chlorinating, as any mud clumps, allowed to remain in the pipe, shield bacteria from contact with the strong

chlorine solution and allow them to contaminate the supply for months afterward. Cleaning is accomplished by laying clean pipe lengths in dry trenches or by drawing a brush, made by bunching sufficient mop heads, by a rope through the pipe, keeping a length or so behind the end. As the pipe laying progresses, the end should be kept plugged to prevent entry of debris. For effectual disinfection the packing must be free from contamination. Jute is best disinfected by spreading it out on a clean floor and dusting on IHTH powder. Soaking in 1% available chlorine solution is satisfactory, provided the fibers are dried before ramming in the joint. Hot lead may be poured on wet packing if it is first wetted with kerosene. Sterile packing is available in fibers and rubber rings.

Repairs in a short length can be disinfected by first cleaning and then swabbing the exposed interiors with a strong hypochlorite solution, about 1% available chlorine. New small appurtenances, like repaired meters, cocks, and fittings for insertion in consumer services, should also be flushed before installation with hypochlorite solution. Length of contact with corroding meter parts should be kept to a minimum.

Long newly-laid lines should be filled with water containing 50 p.p.m. chlorine and allowed to stand preferably overnight; stronger doses may be used if the soaking period is less. If only one-half an hour contact is allowed, a dosage of 150 p.p.m. is desirable. When only flash contact is possible, as with fairly clean, short lines that must be restored to service immediately following repairs or changes, a slug of dilute chlorine solution, containing up to 10,000 p.p.m. chlorine (1% available chlorine solution) is passed slowly through the questionable sections. The most certain method is to feed a chlorine solution, either from a hypochlorite barrel or a chlorine cylinder on a platform scale, through an injector discharging through a corporation cock into the new line as it is filled with water or as the old water from the pressure test is displaced. As the chlorine solution is fed, all openings in the main should be closed except

the one closest to the tie-in and possibly also a small relief opening in the far end to prevent full-line back-pressure from opposing the injector. When a high residual, sufficient to give intense orange color with orthotolidin reagent, reaches the first opening, the next opening in line should be opened and the first closed. By diluting the sample with distilled water, the residual may be made to fall in the measurable green color range and its true value obtained by multiplying the reading by the dilution factor. Usually the sampling openings are fire hydrants. Chlorine concentration, as used here, has sufficient odor that the arrival of the disinfecting solution at an opening can be recognized by smell. If the line has no outlets and is not yet connected, the chlorine solution may be fed through a fire hose from the closest hydrant and discharged at the far end through a smaller size riser tapped into a plug end.

In isolated cases, pressure water for the injector is supplied through a booster pump, such as a fire engine or a portable gasoline-driven unit. After standing the recommended 3 to 24-hour period, the strong solution is flushed out, using the same sequence of openings as before, until the customary residual recurs at each point. The advantage of this method is that contact throughout the pipe-line is certain and uniform.

A simpler but less certain, hence less desirable, method for chlorinating a new line consists in placing a measured quantity of dry hypochlorite powder, preferably HTH or Perchloron, in every second or third joint. The turbulence of the admitted water on opening the valve at the tie-in is depended on to dissolve and mix the contents. A serious objection to this method is that the current of incoming water will sweep away the hypochlorite powder from the near end of the pipe-line. This effect leaves the closer end of the line less concentrated as the hypochlorite is washed forward. Some correction for this tendency is possible if the new line is tied in at both ends and its contents surged in one direction and then in the other.

Hypochlorite solution may be applied continuously to a new line by means of a hypochlorinator or a stirrup pump.

In flushing out the disinfecting solution, fresh water should be admitted into the new line through as many tie-ins as exist, so that no slugs of chlorine solution remain between these junctions and the closest opening. After clearing from each direction, all valves are opened for simultaneous flush-out from all directions.

Bacterial samples should be taken and a satisfactory report received, before the pipe-line is allowed to function. A good sampling point is the corporation cock to which the chlorinator was attached. Fire hydrants are more difficult to flame and should be allowed to flow full for several minutes at least, in order to remove any pollution that may have entered through the weep hole. Keeping pressure inside a hydrant barrel by placing a valve on the nozzle is not recommended, as back-syphonage is certain to occur through the weep hole if pressure is shut off at the tie-in or if the line drains by gravity through other such openings at lower levels.

**Calculations for Pipe-Line Chlorination.** The amount of chlorine or hypochlorite required to disinfect a main is calculated from the size of pipe, its length, the per cent of available chlorine in the material, and the residual desired. To this is added 10% to allow for chlorine demand of the water and inaccuracies in feed. Steps in the calculation and a specific example are given below.

Volume of pipe-line (cu. ft.)

$$= 3.14 \times \left( \frac{\text{diameter (in.)}}{2 \times 12} \right)^2 \times \text{length (ft.)}$$

$$\text{gallons} = 3.14 \times \left( \frac{\text{diameter (in.)}}{2 \times 12} \right)^2 \times \text{length (ft.)} \times 7.5$$

Dosage, pounds per million

$$\text{gallons (lb./MG)} = \frac{50 \text{ p.p.m.} \times 1.10}{\% \text{ available chlorine}} \times 100 \times 8.3$$

Quantity needed, pounds

$$\begin{aligned}
 &= \frac{\text{volume of pipe-line (gal.)}}{1,000,000} \times \text{dosage (lb./MG)} \\
 &= 3.14 \times \left( \frac{\text{diameter (in.)}^2}{2 \times 12} \right) \times \text{length (ft.)} \times \frac{1}{1,000,000} \\
 &\quad \times \frac{50 \times 1.10}{\% \text{ avail. chlorine}} \times 100 \times 8.3 \\
 &= \frac{0.00187}{\% \text{ avail. chlorine}} \times \text{diameter (in.)}^2 \times \text{length (ft.)}
 \end{aligned}$$

For short lengths of pipe, smaller than 20 inches in diameter, the weights needed are so small that expression in ounces is preferable; to do this multiply the last formula by 16.

Quantity needed (ounces)

$$= \frac{0.0299}{\% \text{ avail. chlorine}} \times \text{diameter (in.)}^2 \times \text{length (ft.)}$$

Taking the per cent of available chlorine as 100 for gaseous chlorine, 70 for HTH and allied products, and 33 for bleaching powder, separate formulas may be written as follows:

$$\begin{aligned}
 \text{Chlorine, ounces} &= 0.0003 \times \text{diameter (in.)}^2 \times \text{length (ft.)} \\
 \text{HTH, ounces} &= 0.00043 \times \text{diameter (in.)}^2 \times \text{length (ft.)} \\
 \text{Bleaching powder, ounces} &= \\
 &0.0009 \times \text{diameter (in.)}^2 \times \text{length (ft.)}
 \end{aligned}$$

*Example.* Find the amount of HTH required to disinfect 1000 feet of 10-inch main.

*Calculation.* Substituting in the corresponding formula above, the following statement is obtained:

$$\begin{aligned}
 \text{HTH, ounces} &= 0.00043 \times 10 \times 10 \times 1000 \\
 &= 43 \text{ oz.}
 \end{aligned}$$

In this way the dosage figures in Table 4 were calculated.



TABLE 4

Amount of Materials Needed to Chlorinate Pipe-Lines  
50 p.p.m. residual, approximately. 12 to 24 hours' contact.

| Pipe<br>Diameter<br>Inches | <i>Ounces per 100-Foot Length</i> |       |                     |
|----------------------------|-----------------------------------|-------|---------------------|
|                            | Chlorine                          | HTH   | Bleaching<br>Powder |
| 4                          | 0.48                              | 0.69  | 1.44                |
| 6                          | 1.08                              | 1.55  | 3.24                |
| 8                          | 1.92                              | 2.75  | 5.76                |
| 10                         | 3.00                              | 4.30  | 9.00                |
| 12                         | 4.32                              | 6.19  | 12.96               |
| 16                         | 7.68                              | 11.00 | 23.04               |
| 20                         | 12.00                             | 17.19 | 36.00               |

**Miscellaneous and Emergency Chlorination.** Other specialty chlorination jobs are those required in well construction, such as the slush-pit, gravel and completed structure; in emergency chlorination of tanks and reservoirs following damage, cleaning, or repairs; and in temporary chlorination of ground-water supplies. Application of chlorine in well disinfection is discussed in Chapter 3. Tanks and reservoirs are disinfected by dosing with 0.5 to 2 p.p.m. chlorine. Higher residuals may be selected where the degree of contamination warrants it and the water can be run out to waste. Temporary chlorination of untreated ground-water supplies is required during a continued show of contamination in such systems; the application is usually by means of a constant level orifice type of hypochlorinator to give residuals from 0.2 p.p.m. upward, as governed by bacterial tests.

**Disinfection on a Small Scale.** To disinfect small quantities of water, the following rough formula is useful: dissolve one teaspoonful of bleaching powder in a pint of water; let settle. One teaspoonful of this stock solution will treat two gallons of drinking water. Contact time should be at least half an hour.

One of the following liquid preparations may be added to

disinfect a gallon of water; a half-hour standing time should elapse before drinking.

| <i>Preparation</i>  | <i>Drops per Gallon of Water</i> |
|---|----------------------------------|
| Zonite  | 10                               |
| Liquid bleach (5% chlorine) Chlorox, Dazzle,<br>Rainbow, etc. | 2                                |
| Tincture of iodine  | 4                                |

**Chlorination Complaints.** Consumer complaints from a chlorinated supply usually arise from unpleasant medicinal tastes caused by high dosage, or by chloro-compounds, particularly when using simple post-chlorination. When for sanitary reasons, the residual cannot be reduced, tastes are controlled in many cases by the use of the ammonia-chlorine method. Break-point chlorination, followed by dechlorination or by residual fixation as chloramines, also gives excellent taste control.

Goldfish are killed when residuals exceed 0.5 to 1.0 p.p.m. A slightly higher residual may be withstood when fish bowls are changed daily than when the water flow is continuous. Chlorine tolerance varies with the species in the following order: Shubunkin, Common, Fantail. Complaints of their death at lower residuals may be due to other causes, notably temperature shock when their water bowl has been changed.

The effect of chlorine in water on most vegetation is negligible. Studies on lawn grass show that residuals grossly beyond the range of palatability (around 50 p.p.m.) must be reached before grass plots are burned or damaged.

## SECTION 3. OTHER SPECIAL TREATMENTS

### CHAPTER 10

## IRON REMOVAL

**Objections.** Dissolved iron, in greater concentrations than about 0.3 p.p.m., is objectionable in water supplies because it causes:

1. *Turbidity.* On release of carbon dioxide from ground water and exposure to atmospheric oxygen in reservoirs, the iron previously in solution is converted into a finely divided precipitate which makes the water unappealing. Sediments deposited in pipe-lines are stirred up by heavy flows.

2. *Stains.* Iron deposits form a rusty stain on plumbing fixtures. Fabrics washed in iron bearing water become yellowed from the sediments and tan soap curds. Yellow cores are formed in ice blocks.

3. *Bacterial Deposits.* A group of higher bacteria, *Crenothrix*, *Leptothrix*, and some *Spirillum*, have the unique power to consume dissolved iron as a food and excrete it to form a sheath. Their colonies reduce carrying capacity of a pipe-line. On dying they break off, discharge through consumers' taps, and cause odor of decomposition. This odor, resembling that of stale condensed milk, is especially marked in hot water-lines.

4. *Darkening of Industrial Products.* Iron causes beers to darken by forming an ink with the tannin from hops. Dye houses produce off colors. Manufacture of white paper requires iron-free water.

Some bottled spring waters have a characteristic sweetish

mineral taste due to iron. Manganese, higher than 0.1 p.p.m., also causes objectionable stains and in higher concentrations causes balling in sand filters.

**Sources.** Clear deep well-waters frequently contain iron dissolved in the form of ferrous bicarbonate. This form is readily precipitated as rust or ferric hydroxide when sufficient carbon dioxide has escaped and oxygen has been admitted as by air lifts, exposure overnight in a vented casing, open reservoir storage, or in shallow wells. Swamp waters may contain iron in solution as an organic compound or in the colloidal state. Under certain conditions, iron is corroded from mains and appears in the form of red water.

**Factors in Removal.** Iron may be removed from most waters by use of the methods described below. The choice of a method is influenced by characteristics of the water, such as the amount of carbon dioxide, total solids, hardness, pH and presence of manganese. Organic and colloidal iron compounds are eliminated only by coagulation or break-point chlorination. In any case, the applicability of a method should be proven by jar test, and preferably by a pilot plant, before adoption for local treatment.

### *METHODS OF REMOVAL*

**Direct Precipitation.** Sufficient lime or other alkali will combine with the carbon dioxide and precipitate iron as green ferrous hydroxide and ferrous carbonate. Lime is fed into the pipe from the well, and after a short contact period in a reaction compartment, the water is filtered under pressure in the lower portion of the same vessel. Since treatment is conducted in a closed system, there is no opportunity to dissolve atmospheric oxygen; the effluent is therefore, non-corrosive.

## OXIDATION AND FILTRATION METHODS

**Aeration.** Dissolved iron is oxidized by contacting the water with air; oxidized iron compounds precipitate much more readily than iron in its original ferrous state. One p.p.m. of oxygen will remove 9 p.p.m. of iron. The product becomes a form of rust, namely a hydrated ferric oxide. Oxidation is brought about by some type of aerator. Coke trays are the most effective because in addition to removing carbon dioxide and efficiently saturating with oxygen, the surfaces upon which the iron plates out also aid further precipitation. Part of the removal is believed to be due to organisms. Following this oxidation, a settling or contact reservoir is provided so that sluggishly forming precipitates have an opportunity to floc and settle out. Final removal of floc still in suspension is accomplished in a sand filter.

Coke trays should be cleaned off when the iron oxide coating becomes too voluminous and clogs the opening. This is done by removal of the pieces to a surface where they may be hosed clean. A quicker method is to dump the charge into a rotating drum and agitate for about a minute. Contact beds, filled with coke or rock, also need cleaning when the deposits become too bulky; the contact media may be left out if the water is high in iron.

Employing similar principles, the so-called "Ferfilter" consists of a rotary distributor which aerates the water to remove carbon dioxide and oxidizes bicarbonate-bound iron and manganese by discharge directly over an anthracite trickling filter. A one-hour post-reaction period should be provided in the clear well. Accumulated iron and manganese deposits are removed by backwashing.

**Pressure Aeration.** Hard waters, low in carbon dioxide, may precipitate iron as rust if aerated with just a "sniffle" of air introduced into the line from the well. When using this method, the water discharges on a splash board above a filter in a closed

tank. Air and carbon dioxide escape through a seal at the top of the shell. When more aeration is required, a contact bed of lava, gravel, coke or limestone is mounted on a shelf above the filter unit; air is introduced below this bed and contacts the trickling water countercurrently. In some modifications, lime and alum or chlorine is fed back into the line in advance of the contact bed to aid in coagulating the finely divided iron precipitate or to oxidize manganese.

**The Role of Alkalies and Softening.** If the well water is high in carbon dioxide, low in total solids and hardness, of low pH or with manganese present, iron precipitation will be hampered. Alkali, generally lime, will help removal by destroying the acidity. Manganese cannot be removed by simple aeration except at high pH; so, when present, lime must be added to produce a pH higher than 9.2. The reason that iron and manganese are easily removed at high pH is that their solubilities are lowered and their precipitates readily oxidized to ferric and manganic oxides, respectively. In high manganese bearing waters, low in dissolved iron, ferric sulfate may be effectively added to produce a drag-net floc. A recently developed method of removal consists simply in passing iron and manganese bearing water, previously adjusted between pH 7.0 to 9.0 for iron removal, or from pH 8.5 to 10.0 for manganese removal, through a surface-active sludge composed of their precipitates.

Coagulation, in all cases, aids by promoting the formation of the precipitates and their settling before filtration. Lime-softened waters are iron and manganese free as, in the pH range required for this process, precipitation of these minerals is practically completed. Therefore, softening is sometimes referred to as a distinct method for iron removal.

A popular method of alkalizing water in Europe is by passage through beds of "magn-masse," a mixture of magnesium oxide and calcium carbonate formed by controlled burning of dolomitic limestone. Manganese is removed as well as iron.

Backwashing removes iron and manganese precipitates; depletion of magnesium oxide is refilled by more magno-masse. Beds of burnt limestone perform similarly.

**Superchlorination.** Being a strong oxidizing agent, chlorine readily transforms the soluble ferrous bicarbonate of ground waters into the less soluble ferric form, which separates out as the hydrated oxide. This iron floc forms at all pH values met in practice, leaving the supernatant water clear and iron free. The reaction is usually rapid and, after a suitable detention period, the water may be used following sand filtration. Theoretically, 1.0 p.p.m. of iron requires 0.64 p.p.m. of chlorine for oxidation, or 5.3 lb. of chlorine per 1.0 p.p.m. of iron per million gallons of water. When manganese also is oxidized, its chlorine demand is 1.29 p.p.m. per 1.0 p.p.m. of manganese. In a small system providing sufficient settling period, the water may be drawn for consumption without filtration. By exceeding the break-point, organic iron compounds are destroyed, therefore, this method is applicable for dark swamp waters. Dechlorination is effected by sulfur dioxide or other usual reagents. With well water, the whole process may be conducted in a closed system, thus avoiding oxygen pick-up and its attendant corrosive properties.

**Reversible Contact Oxidation.** Higher oxides of manganese have the useful property of transferring some of their oxygen to soluble iron when water is passed through beds of contact material on which these oxides are plated out. Iron thus oxidized is filtered out in the bed. Filter sand, anthraflit, crushed manganese ore (pyrolusite), or a durable zeolite are coated with these active oxides by wetting with a solution of manganous chloride followed by oxidation with potassium permanganate. The accumulation of precipitated iron oxide should be cleared off by backwashing the filter daily. When the performance falls off, the unit should be regenerated by restoring the reduced manganese oxides to their original state, using either potassium permanganate or hypochlorite solutions.

## OTHER METHODS OF REMOVAL

**Base Exchange Zeolites.** Base exchange zeolites, of the type widely used in softening water, function by swapping off some unobjectionable component in their composition, like sodium, for dissolved iron and manganese when water is passed through such a bed. All iron must be in the ferrous state, and the water should be clear, otherwise the active grains become coated over and thus made ineffective.

Zeolites will continue to remove iron even when the bed has been exhausted for purposes of softening. However, such a starved bed will not remove manganese. Regeneration of a zeolite bed is accomplished by soaking with a strong brine solution, followed by a rinse to remove excess brine.

By using split treatment, with a certain portion of the water undergoing softening by zeolite and the remainder passing through a higher manganese oxide contact filter or a starved zeolite unit, any desired degree of controlled softening and iron removal may be obtained. In this way, complete softening to nearly zero hardness is unnecessary when iron and manganese are to be reduced within the 0.3 p.p.m. limit.

Carbonaceous zeolites, derived from coal, also have the ability to exchange sodium or hydrogen, according to their operating cycle, for iron and manganese.

**Resins.** Although still in the experimental stage or beyond the price range for municipal use, many new compounds possess iron-removal properties through adsorption, a surface retention which lies between true chemical reaction and physical absorption. Many phenolic resins and plastics act in this manner, as do lignins prepared from corn cobs.

**Sequestration.** Sodium hexametaphosphate, known as Calgon, will combine with dissolved iron in the unoxidized state to form a so-called stable complex, retaining the iron in solution. Identity and properties of the dissolved iron are lost by its association with the reagent. This action is termed seques-



tration. Iron so held will not begin to precipitate for about 15 hours. To inhibit discoloration completely, 4 p.p.m. of Calgon is required ordinarily for every 1 p.p.m. of iron. Where demands for clearness in the water may be relaxed, smaller doses suffice down to 1 p.p.m. of Calgon per 1 p.p.m. of iron. Injection must precede contact with air, as no complex is formed after the iron is oxidized. Calgon solution may be fed at the casing head of a pump well or may be admitted down to the casing through a tube passed through the vent. In some states, an upper limit to dosage of Calgon has been set by the Department of Health which should be consulted before adoption of this treatment.

**Tests.** Operation of an iron removal plant should include an occasional test of the iron content of various well waters and of the plant effluent. Test methods for iron are given in Chapter 19. Turbidity readings around the system give evidence of satisfactory treatment. Colorimetric pH tests and the alkalinity determination are useful in appraising the carbon dioxide removal in the aerator and in regulating dosage of alkali. Where break-point chlorination is used, the residual should be determined several times daily.

Often the iron problem can be lessened by avoiding use of certain wells in a battery, except in necessity.

## CHAPTER 11

### SOFTENING

**Definitions.** The process of removing hardness from water is called *softening*. Fundamentally, hardness is due to the presence of calcium and magnesium salts in solution. These substances are dissolved out from deposits that the water has percolated through or drained over, depending on whether or not the supply is ground water or surface water. Common sources of calcium are limestone and gypsum; magnesium is derived from dolomites and widely distributed sulfates.

Hardness is expressed in terms of calcium carbonate ( $\text{CaCO}_3$ ) because this substance is most frequently an important constituent of scales and also because the chemically equivalent weight of any other compound is easily calculated. Ordinarily, a water containing over 100 p.p.m. hardness is rated as hard; over 200 p.p.m. hardness is considered very high. The range in hardness from 50 to 100 p.p.m. is considered as moderately hard or moderately soft according to the point of view of the consumer. Below 50 p.p.m. hardness, a water is known as soft; under 15 p.p.m. hardness, a water is very soft.

Types of hardness are best classified according to the nature of the constituents involved. Thus calcium hardness and magnesium hardness distinguish between the kinds of salts present. Likewise, carbonate and non-carbonate hardness each refer to types of compounds in which the calcium and magnesium are combined. An obsolete classification into temporary and permanent hardness, according to the effect of boiling upon a water sample, has been found inaccurate and misleading. The classifications now observed are helpful in choosing the softening method best adapted to a particular supply.

**Objections to Hard Water.** Hard waters are economically objectionable; the following faults are typical:

1. *Soap Waste.* Lather is formed in hard water by ordinary soaps only with difficulty. It is this property that gave rise to the term hard water; consumers noted that suds were hard to form in such waters. Actually soap must soften water before suds can remain permanently. The soap so used is wasted because by proper softening the water should lather with a minimum of soap. The amount of soap lost in waters of varying hardness may be estimated by means of Foulk's formula:

$$\frac{\text{[Pounds of soap per 1,000 gallons]}}{2 + 0.2 \times \text{hardness (p.p.m. as CaCO}_3\text{)}}$$

2. *Effect of Soap Curds.* The soap wasted in hard water reacts with the calcium and magnesium content to produce curdy precipitates. These curds form the ring around the bath tub and lavatories. By their deposition in and between threads, white fabrics become greyish when washed in hard water. Extra effort to whiten and to rinse out such soap curds shorten the life of textiles. Curds harbor bacteria. Restaurant plates washed in hard water tend to retain bacteria.

3. *Incrustation.* Hard waters, without sufficient carbon dioxide to keep carbonates in solution, will incrust cold water piping and meters. In cooling coils, and especially in hot water lines, the scale deposits much faster and more completely. Hard waters may clog a boiler tube entirely with scale. Even a thin scale causes a serious waste of fuel in steam boilers; scale thickness of 1/50 to 1/9 inch will consume roughly 7 to 16% of the fuel cost. Once formed, scale is described as hard or soft, according to the work required for its removal. Hard waters form scales in kitchen pots. With some vegetables, as peas, hard waters toughen the skin and degrade the product for canning. For many manufacturing purposes, hard waters are absolutely unsuited.

4. *Sanitary Hazard.* While hardness in a municipal supply

has no direct sanitary objection, some consumers, by seeking alternate softer supplies, such as private cisterns and wells, may substitute an unsafe source in place of a safe water. In regions of excessive hardness, consumers frequently install dual plumbing systems, one for hard potable water, and the other to carry soft water, usually of questionable safety, for washing and bathing.

**Feasibility of Softening.** The economic advantage of softening can be appreciated from the fact that one pound of lime, costing half a cent will save 20 pounds of soap worth about \$3.00 in the water used. The saving thus indicated, one of 600 times the cost, must be viewed according to the fraction of the per capita consumption used directly with soap. Allowing 1.2 gallons for sudsing, out of the average 100 gallons per capita per day consumed in American cities, the savings reduce to  $600 \times \frac{1.2}{100}$  or 7.2 times the cost. This gross figure is based on chemical costs only; if allowance is made for plant and labor costs, the advantage of softening shrinks further to a net savings based on soap cost alone of about 3 times its cost. To this economy should be added the financial value of other benefits, especially those to users of heating and cooling equipment.

A common lower limit to which many municipal plants soften their hard supply is about 40 to 80 p.p.m. Further softening requires closer attention to anti-corrosion treatment. Water approaching zero hardness causes criticism due to difficulty in rinsing out soap suds. Costs for more complete softening should be borne by special consumers themselves.

## SOFTENING METHODS

Methods of softening applicable to municipal supplies are limited to partial softening by lime, the lime-soda treatment, and to so-called base exchange by means of siliceous zeolites.

Other methods used only by specialized industries include barium softening, softening by carbonaceous zeolites, sequestration by hexametaphosphates, and demineralization by synthetic resins.

**Partial Lime Softening.** Lime softening can accomplish the following results: (1) remove free carbon dioxide, (2) reduce hardness due to calcium bicarbonate, and (3) almost completely eliminate magnesium in any form if desired.

In partial lime softening, the most advantageous manner for using lime, only the first two effects are expected. When carbon dioxide is higher than about 20 p.p.m., the water is first aerated to reduce the lime requirement. The action of lime on calcium bicarbonate is to form a precipitate of calcium carbonate which removes both the original calcium bicarbonate and the added lime. Depending on conditions, a residual calcium hardness from about 20 to 40 p.p.m. will remain. To produce this softening, enough lime is added to convert bicarbonate into normal carbonate. Simple laboratory tests for these items and their interpretation are given in Chapter 19.

Where applicable, partial lime softening is the cheapest method of reducing hardness; this process is suited to waters of high carbonate, low non-carbonate, and low magnesium hardness. Even though no magnesium reduction is intended, liming the water to react with all bicarbonate present will incidentally remove about 10% of the magnesium.

Lime, chemically considered, is calcium oxide. Commercially, this material is known as quicklime or unslaked lime; it contains normally from about 6 to 12% of impurities. Before feeding into the basins, quicklime is slaked or combined chemically with water to form calcium hydroxide; enough water is added to make a so-called milk of lime which is generally proportioned by a solution feed. Slaked lime or dry calcium hydroxide is also commonly used; impurities may be reduced during conversion to as low as 2 to 7%. For small plants,

slaked lime is preferable to quicklime because the detail involved in slaking is avoided and the powder is conveniently discharged from a dry feed machine.

An approximate calculation of the theoretical dosage of unslaked lime for partial softening is based on the relations shown in Table 5.

TABLE 5

Unslaked Lime Required Theoretically to React with  
1 p.p.m. of Various Substances

| Item   | Unslaked<br>Lime<br>p.p.m. | Remarks  |
|--|----------------------------|--|
| A. Carbon dioxide                                      | 1.27                       | Removed as calcium carbonate   |
| B. Bicarbonate hardness,<br>as $\text{CaCO}_3$         | 0.56                       | Removed as calcium carbonate   |
| <i>Incidental effects</i>                              |                            |  |
| C. Residual bicarbonate alkalinity, as $\text{CaCO}_3$ | 0.56                       | Lime is spared   |
| D. Caustic alkalinity, as $\text{CaCO}_3$              | 0.56                       | Lime additionally required   |
| E. Magnesium   | 2.32                       | Based on magnesium actually removed; commonly a 10% reduction        |
| <i>F. Coagulant</i>                                    |                            |  |
| Filter alum  | 0.25                       | Consumed in reaction with the coagulant                              |
| Copperas   | 0.20                       |  |
| Ferrie sulfate   | 0.42                       |  |
| Sodium aluminate                                       | -0.34                      | Lime is spared with this alkaline coagulant                          |
| G. pH change of water                                  | —                          | This absorbs only a minute amount of lime when pH is below about 9.6 |

Since commercial lime, either unslaked or slaked, contain impurities which must be allowed for when calculating dosage requirements, the theoretical equivalents in Table 5 must be multiplied by suitable factors. In Table 6 are stated typical factors for both varieties of lime. In the absence of an exact analysis showing the purity of the lime, these figures are sufficiently close for satisfactory estimates.

TABLE 6  
Conversion Factors for Limes

| Variety                  | Approximate Purity % | Content of Pure Calcium Oxide % | Factor to Multiply Theoretical Unslaked Lime Dose by |
|--------------------------|----------------------|---------------------------------|--|
| Commercial quicklime     | 90                   | 90                              | 1.11   |
| Commercial hydrated lime | 93                   | 71                              | 1.41   |

*Example.* A well water containing free carbon dioxide 15 p.p.m., bicarbonate hardness 175 p.p.m., as  $\text{CaCO}_3$ , and magnesium 20 p.p.m. is softened with hydrated lime. For coagulation, 5 p.p.m. copperas was used. A test of the softened water showed that 5 p.p.m. residual bicarbonate alkalinity still remained. Estimate the amount of lime used per million gallons.

*Calculations*

| Item                         | Pure Quicklime Dose p.p.m.                |
|------------------------------|---|
| Carbon dioxide               | $15 \times 1.27 = 19.1$                   |
| Bicarbonate hardness         | $175 \times 0.56 = 98.1$                  |
| Magnesium (assumed)          | $0.10 \times 20 \times 2.32 = 4.6$        |
| Copperas                     | $5 \times 0.20 = 1.0$                     |
|                              | <u>122.8</u>                              |
| Bicarbonate residue          | $5 \times 0.56 = 2.8$                     |
| Pure quicklime dose p.p.m.   | <u>120.0</u>                              |
| Commercial slaked lime dose: |   |
| Pounds per million gallon    | $= 8.3 \times 1.41 \times 120.0 = 1,406.$ |

The pH value of water treated to eliminate bicarbonates, but without caustic alkalinity, is near 10.0. As its total normal carbonate alkalinity is increased, the pH value rises slightly.

The equipment in a partial lime softening plant consists of the conventional items for water treatment. These include storage space for lime in sacks or bins for reserve in bulk; a dry feed machine if slaked lime is used, or a proportioner if milk of lime is fed; a mechanical mixer or high-velocity channeled mixing basins, a quick mix is of no benefit since the softening reactions are slow; and a sedimentation basin volume of two to four hours' flow. A coagulant, copperas outstanding

at this high pH, is generally introduced by quick mix just before sedimentation to aid in settling the precipitates. Upflow sedimentation tanks that provide dosing in contact with sludge and filtration through the sludge blanket are well adapted for partial lime softening, particularly when a high slurry concentration is retained.

Filtration follows closely the principles discussed in Chapter 8. Since the filter influent may still contain sluggishly forming precipitates, the water is said to be supersaturated. Some of this product coats out on the filter sand, increasing the grain size and cementing the gravel, unless attention is directed to prevent this effect. High-velocity backwash and surface-wash devices are desirable. Chemical methods for controlling filter sand incrustation include (a) recarbonation and (b) metaphosphate treatment. Recarbonation to give about 5 p.p.m. bicarbonate alkalinity just before filtration converts some of the insoluble calcium carbonate to the soluble bicarbonate form thus destroying considerable supersaturation. Phosphoric and sulfuric acids are sometimes used for this purpose. Metaphosphates protect filter sand by interfering with the crystal formation on the grains. Where sand growth is not controlled, a small grain size about 0.35 mm. effective size is desirable, so that replacement is not required after only a few years' use.

As the pH of the water ranges from about 9.4 to 10.0, its silica content will be increased slightly by passage through new sand. In industrial plants where silica is undesirable, this effect is avoided by the use of pre-coated sand grains or by anthracite filters. Lime treatment, sedimentation and filtration, usually provide a safe water bacterially; however, a final chlorination to 0.2 p.p.m. orthotolidin residual is added as a margin of safety.

Advantages of the partial lime softening process are:

1. This is the most economical method where applicable.
2. Residual hardness caused by calcium bicarbonate may be as low as 20 p.p.m., as  $\text{CaCO}_3$ .
3. Total solids are reduced.



4. Turbidity and bacteria are removed.
5. Color and odors may be reduced.
6. Iron and manganese are eliminated.
7. The plant effluent is non-corrosive.
8. With waters low in turbidity and magnesium, the lime sludge may be burnt in a kiln for re-use in the treatment process.

Disadvantages of this method are readily corrected in most cases; they include:

1. Sludge volume must be disposed by lagooning, pumping into a receiving stream, or recovered, as in a few recent cases, by dewatering and drying to yield calcium carbonate.
2. Attentive and informed supervision is necessary.
3. The filters and distribution system become coated, except where controlled.

*Negative Hardness.* When the sum of the calcium and magnesium, as equivalent calcium carbonate, is less than the alkalinity, the difference is due to the presence of sodium bicarbonate. Non-carbonate hardness is absent. This condition is termed *negative hardness* because the lime dose for partial softening is determined by subtracting the negative hardness from the total alkalinity before multiplying by the factor 0.56 as given in Table 5. In this case, there is no need to convert the sodium bicarbonate into sodium carbonate. However, if magnesium is to be removed by the excess lime method, the calculation of theoretical dosage is not affected by negative hardness.

**Excess Lime Method.** Excess lime treatment consists in liming the water to about 50 p.p.m. caustic alkalinity. At the resulting high pH (about 10.5), the magnesium precipitate is settled out; the excess lime is next removed either by blending in some raw water or by recarbonation to pH 9.4. At this pH value, the calcium carbonate formed from the excess lime has a minimum solubility of 13 p.p.m. The calcium carbonate so precipitated is settled out in a secondary sedimentation basin.

A second recarbonation is given the settled water just prior to filtration in order to control incrustation in the filter beds.

Recarbonation consists in passing carbon dioxide through the water; the reaction is practically instantaneous. About 60 to 80% of the carbon dioxide is effectively absorbed. The source of carbon dioxide may be from coke, oil, or gas fires or from Diesel engine exhaust. Carbon dioxide may be introduced into the water by bubbling through diffuser grids or plates, by injection, or by underwater combustion in a special gas burner.

The excess lime method is not so economical as partial softening because of the high lime dosage required. This method will soften the water to about 20 to 25 p.p.m. carbonate hardness. Magnesium may be reduced to 3 p.p.m. If the magnesium is present as non-carbonate hardness, magnesium will merely be replaced by calcium from the lime; although magnesium is removed from the water an equivalent amount of calcium hardness is introduced. At the high pH used, bacteria that cause intestinal disease are destroyed. Filter influents may be practically sterile. Final chlorination to 0.2 p.p.m. residual is furnished as an added safety precaution.

The same disadvantages that apply to partial lime softening also attach to excess lime softening but in a greater degree.

**Lime-Soda Method.** In this method, lime used as before to reduce carbonate hardness, is followed by soda ash to react with the non-carbonate hardness. The amount of soda ash needed may be estimated from these relations:

1. One p.p.m. non-carbonate hardness requires 1.06 p.p.m. pure sodium carbonate.
2. Purity of commercial soda ash may be considered to be 98%.

A slight excess of soda ash is commonly used. Jar tests are always desirable when planning a softening treatment. This is particularly true when high soda ash dosage is needed, as there is a tendency for complex reactions to hamper the softening

action, particularly in cold water. This effect may be overcome in a number of ways, including excess liming, split treatment, use of aluminum coagulants, return sludge and sludge blanket upflow tanks. When used in conjunction with lime, the soda ash should be added separately. Mixing these chemicals destroys the non-carbonate softening power. Soda ash can be fed through a dry feed machine. Its point of application in the plant should be after the lime precipitates have been well formed.

Reaction of non-carbonate hardness with soda ash does not materially affect the amount of dissolved solids; the action is merely a substitution of sodium for the non-carbonate calcium. The lime-soda ash method may be controlled by proper selection of pH to remove the calcium from a water without much reduction in magnesium. This possibility is important for industries using considerable cooling water in which magnesium hardness is not detrimental, and where economy in cost of chemicals is desired. Only the lime feed will reduce the amount of dissolved solids, generally in the ratio of nearly 3.5 p.p.m. solids removed per one p.p.m. of lime. Close supervision is needed at a lime-soda softening plant. Furthermore, as soda ash is an expensive chemical, this method of treatment is the least popular of municipal softening processes.

For this application, the Spiractor, a conical upflow vessel into whose bottom the raw water and chemicals are admitted through spirally spaced nozzles to produce turbulence within the reaction bed of calcium carbonate granules, is claimed to reduce softening time to less than five minutes. The precipitate forms directly on the granules which are emptied when oversized; disposal of a voluminous wet sludge is thus avoided. Effluent from the Spiractor is passed to the filters.

**Tests.** A chemical softening plant should have well organized laboratory control. Routine tests, some of them performed several times daily, should include pH, alkalinity, hardness, and carbonate stability. When using a surface supply subject to

fluctuations in composition, its pH, alkalinity, and hardness should be checked as frequently as necessary. Jar tests also are useful guides. Methods for conducting these tests are given in Chapter 19.

**Zeolite Softening.** The zeolites used for municipal softening belong to a group of materials known as aluminosilicates. When hard water is passed through a bed of zeolites, the calcium and magnesium is removed by becoming loosely-combined chemically with the zeolite grains. Sodium from the zeolite mass at the same time is released into the water. This swapping action is known as base exchange and is the principle of this mode of softening. Eventually when all the replaceable sodium in the zeolite has been substituted by calcium and magnesium, the softening action necessarily stops. A valuable property of zeolites is that an exhausted bed may be revived by applying a strong brine made from common salt. This regeneration restores sodium into the zeolite composition and displaces the calcium and magnesium. Regeneration is thus effected simply by reversing the reactions that occur while softening hard water. The spent brine contains the calcium and magnesium that have been forced from the zeolite. After rinsing out the brine solution, the bed is ready for another softening operation. This cycle of operation may be repeated indefinitely without material loss in performance. Fracture of grains and loss of fines may cause a shrinkage of about 3% per year in the volume of the bed.

**Equipment.** In practice, the zeolite is usually placed in a vessel resembling a pressure filter. The depth of bed ranges from 2.5 to 4 feet and over. Upflow and downflow units are available. In the upflow type, hard water is admitted through underdrains beneath the zeolite bed; the softened effluent is removed at the top. In this system the bed is kept expanded by the upward flow velocity, commonly 4 to 8 g.p.m. per square foot. There is no need for routine backwashing if either the softening or rinsing velocity exceeds 6 g.p.m. per square foot.

The downflow softener is patterned exactly like a pressure type sand filter with wash water gutters, gravel layer and manifold underdrains. Downward softening velocities are generally 3 to 5 g.p.m. per square foot. Any turbidity present collects on top of the zeolite bed just as on a sand filter. Consequently, a downflow softener may require routine backwashing at a 6 to 8 g.p.m. per square foot rate, in order to maintain the desired rate of filtration. If the applied water is not fairly clear, a downflow zeolite bed should be preceded by a rapid sand filter.

Siliceous zeolites, as used for public supplies, are of two types: natural and synthetic. The naturally occurring zeolite is strip mined and then processed to remove inert matter and increase its hardness. The finished grains are slightly larger than filter sand and green in color, hence the name "greensand." Synthetic zeolites, made by various chemical processes, are white irregularly shaped fragments about half the size of a pea. Natural zeolites remove about 2,500 grains of hardness per cubic foot; synthetic zeolites have exchange capacities ranging from 9,000 to 12,000 grains per cubic foot. Natural greensands are less affected by the nature of the water passing through them; slight turbidity or appreciable iron is not harmful. Synthetic zeolites may be damaged if the applied water varies much from pH 7 to 8.

**Salt Requirement.** Fundamentally, the chemical consumed in the zeolite softening process is salt, so the economy of this process depends on the salt requirement for regeneration. Ordinarily, municipal plants may expect to use 0.35 to 0.45 pounds of salt per 1,000 grains of hardness removed.

If the original water is not excessively hard, is low in sodium, and if the softener unit is not worked to its maximum capacity but is allowed to deliver a water containing a residual hardness, the lower figure for salt consumption will apply. Also complete softening is undesirable because the effluent becomes highly corrosive. Softened water is usually blended with hard

water, by means of a by-pass, to give a final product with 60 to 80 p.p.m. hardness.

Sufficient brine storage for a week's use is commonly provided in concrete, wood, or heavily tarred steel tanks. An excess of salt is placed in a dissolving basket and make-up water admitted through a float-controlled valve. In some installations, the saturated brine is withdrawn through gravel-covered underdrains and transferred to a small dosing tank. A saturated salt solution contains 26% sodium chloride or 2.66 pounds of salt per gallon; its specific gravity is 1.205. Brine is pumped or injected with sufficient dilution water into the distribution piping inside the zeolite unit to give a 5 to 10% salt concentration. With greensand beds, the brine flows through in continuous slow passage followed by the rinse; synthetic zeolite beds require a short soaking period of about 15 minutes' contact time with the brine. The rinse for removal of brine will consume about 10% of the total water output.

The need for salting can be conveniently determined by means of a quick soap test using a special concentrated soap solution. If more than several drops of solution are required to produce suds in a certain volume of sample, the effluent is too hard. After operating a unit for a while, an operator can predict when to regenerate his bed simply by schedule. Knowing the exchange capacity of the zeolite, its volume in cubic feet and the hardness of influent and effluent, it is a simple matter to calculate the volume of water softened during each cycle. Thus a 15-cubic-foot bed which removes 6,000 grains hardness per cubic foot will account for 90,000 grains between brine applications. If the water is softened from 10 g.p.g. down to 1 g.p.g., a net removal of 9 g.p.g., the volume softened during each operating cycle will be  $90,000/9 = 10,000$  gallons. By noting the meter readings, the time for salt treatment can be determined without making the soap test. Over-running a bed beyond its capacity, so-called starving a zeolite, is undesirable

as an extra amount of salt and contact time is required to restore its normal softening capacity.

Typical procedure for regenerating a zeolite softener is as follows:

1. Loosen the bed by a preliminary backwash, unless the unit uses the upflow method.
2. Introduce brine, 5 to 10% strength, into the softener. Allow merely a slow displacement in the case of greensands; let the brine stand 15 minutes in contact with the bed if synthetic zeolite is used.
3. Flush out the bed until free from brine. This is determined by means of a test for excessive chloride, or by using the soap test to indicate when the effluent hardness is below 1 g.p.g.
4. Place the unit in service.

The use of zeolites as a softening method has the following important advantages:

1. Water cannot be overdosed with resultant excess of chemicals appearing in the softened water.
2. No complicated chemical control is needed. A minimum of attendance and supervision is sufficient. Specially built valves simplify operation. Some units are made completely automatic.
3. The final hardness may be controlled to any desired figure by blending untreated hard water with the softener effluent.
4. Iron and manganese also are removed during softening by base exchange action.
5. The spent brine is easily disposed of down the sewer.
6. First cost of installation is lower than that for a lime or lime-soda softening plant. A zeolite plant is much more compact.

Disadvantages of the zeolite methods are:

1. Cost of the salt is higher than chemical costs in a lime-soda plant for removal of a given amount of hardness.

2. Zeolite effluent may need further treatment for corrosion control, either aeration, alkali, or hexametaphosphate.

3. Total solids are slightly increased by replacing hardness with sodium. This fact is usually of no concern in municipal supplies, except when sodium salts are already high and the original water quite hard, in which case taste and slight laxative properties become evident.

4. The applied water must be fairly clear, otherwise preliminary sand filtration is required.

5. A large amount of wash water, 5 to 10%, is used in flushing out the brine.

Despite the expense for the salt, the zeolite method is preferred to excess lime and to the lime-soda treatments because of its positive results and simplicity.

**Tests.** The control test for a zeolite plant is the soap hardness titration on the effluent, using either the standard soap solution or a special concentrated strength to speed and simplify its application. If the influent varies in hardness, this value is also followed by means of the standard soap titration. Completeness of flushing out the brine is determined by a chloride test, supplementing the quick soap test. For checking the performance of the softeners, samples from various metered runs should be composited and tested for pH, total hardness, alkalinity and non-carbonate hardness. An occasional carbonate stability test is needed to guide corrosion control, if alkalis are introduced for this purpose. A white spot plate placed to catch the drip from a faucet will indicate the occurrence of pipe corrosion. Bacterial samples should be routinely collected. If the source of the water or its subsequent exposure warrants chlorination, the orthotolidin residual should be read several times daily.

**Lime-Zeolite Method.** When the original supply is high in both carbonate and non-carbonate hardness, a combination treatment is frequently used. The carbonate hardness is first



removed by partial lime softening in order to secure the advantage of the economy characteristic of this process. The partially softened, settled, recarbonated, and filtered effluent is then passed through zeolite units in order to avoid the complexities of the soda ash treatment. As soda ash is the most expensive common material for softening by a chemical precipitation method, the margin between it and the still costlier base exchange is small enough to be disregarded in considering the convenience and positive performance of zeolites.

**Comparison of Chemical Costs.** The table below shows the theoretical cost of chemicals to soften various types of hardness by the methods indicated. A direct comparison is given in the column headed "cents per p.p.m. hardness per 1,000,000 gallons." It will be observed that bicarbonate hardness can be removed at less cost than non-carbonate hardness, and in a given type, calcium costs less to remove than magnesium when using the chemical precipitation methods. Due to the high concentration of salt in spent brines after regeneration, the chemical cost for operating a zeolite plant exceeds even that for the removal of magnesium non-carbonate hardness in a lime-soda plant. An exchange value of 0.35 per 1,000-grain hardness is assumed for the zeolite. Nevertheless, because of ease of operation, simplicity and low first cost, the zeolite method is commonly selected for all softening requirements except those met by partial lime treatment. Local costs may modify these comparisons considerably.

TABLE 7

Comparison of Chemical Costs to Remove 1 p.p.m. of  
Hardness from 1,000,000 Gallons of Water by  
Various Methods

| Method of<br>Softening    | Type of<br>Hardness<br>Removed | Chemicals<br>Used             | Price<br>\$/Ton | <i>Requirements<br/>per p.p.m.<br/>Hardness<br/>Removed per<br/>Million Gallons</i> |                     |
|---------------------------|--------------------------------|-------------------------------|-----------------|---|---------------------|
|                           |                                |                               |                 | <i>Chemicals Cost</i>   | <i>Pounds Cents</i> |
| Partial lime<br>softening | Calcium<br>bicarbonate         | Quicklime<br>90% purity       | 10.00           | 5.2   | 2.6                 |
| Excess lime<br>method     | Magnesium<br>bicarbonate       | Quicklime<br>90% purity       | 10.00           | 10.4  | 5.2                 |
| Lime-soda                 | Calcium<br>non-carbonate       | Soda ash<br>98% purity        | 30.00           | 9.0   | 13.5                |
| Lime-soda                 | Magnesium<br>non-carbonate     | Soda ash<br>quicklime         | 30.00           | 9.0   | 16.1                |
|                           |                                |                               | 10.00           | 5.2   |                     |
| Zeolite                   | Any type                       | Common salt<br>99 1/2% purity | 23.00           | 20.5  | 23.6                |

## CHAPTER 12

# CORROSION CONTROL

**Nature of Corrosion.** Corrosion of iron products consists of a series of chemical reactions by which iron is transformed into various hydrated oxides commonly called rust. Moisture is essential for this reaction. The type of rusting depends on the kind of exposure; thus, there is atmospheric corrosion, under-water corrosion, soil corrosion, corrosion by active chemicals, corrosion by galvanic action and a variety of other conditions.

**Objections.** Corrosive waters are objectionable for the following reasons:

1. Markedly corrosive supplies cause "red water," a turbid condition in which rust particles are carried in suspension. This occurrence is the most serious manifestation of internal corrosion; it makes the water unappealing in appearance and unacceptable economically.

2. Corrosive water may cause iron stains and give rise to the undesirable complaints associated with the presence of iron.

3. As the pipe walls rust, the iron oxide formed occupies a volume roughly 18 times that of the original metal. Consequently, a corrosive attack on a thin layer will produce a bulky mass which eventually may clog the pipe-line. Carrying capacity is lost and pressures fall off. In order to maintain reasonable pressures in the system, the pressure at the pumping station must be increased. This corrective, a costly one, generally is not provided for. Rust-crusts rob a system of its fire protection value. Reduction in carrying capacity with corrosive supplies may amount to well over 60% in 30 years. Excessive friction loss is the first perceptible effect of corrosion; this damage may be sustained without the appearance of red water.

In extensively corroded mains, the travel of a tapping machine to penetrate the pipe wall will be noticeably greater than in a new pipe.

4. Consumers' plumbing fixtures show pitting, thus failing early and requiring replacement.

**Types of Corrosion.** Under-water corrosion is due primarily to the presence of dissolved oxygen which unites with the iron metal. In *pure water* the rate of corrosion is independent of pH in the range from 4.0 to 11.0, a somewhat wider range than is encountered in natural waters. In this zone of moderate corrosion, the rate of diffusion of dissolved oxygen through the film on the iron surface is the controlling factor; therefore, oxygen concentration and rate of flow largely determine the speed of corrosion. Above pH 11.0, the reaction is greatly slowed; below pH 4.0, the rate of corrosion is speeded considerably, the facility with which hydrogen is evolved being a controlling factor. The effect of the nature of the metal is usually most characteristically shown in acid solutions. Only in these extreme zones does pH influence the corrosion rate in *pure water* at ordinary temperatures. When the water contains other substances in solution, the progress of corrosion will be modified profoundly. In pure water containing only carbon dioxide, the initial rate of corrosion is about one ninth that found with the same amount of oxygen.

Other extraneous conditions may cause special cases of corrosion. Galvanic action occurs whenever two dissimilar metals are in contact. The more electropositive one suffers from the attack. This effect is noted with otherwise non-corrosive waters when a brass and a galvanized fitting are screwed together. Impurities in the metal of a fitting, itself, may set up destructive local currents, finally causing pits to perforate the wall. Electrochemical corrosion may also occur in soils. Soil corrosion is aggravated by the passage of stray currents from power lines; stray current electrolysis concentrates corrosion in pits where the current jumps from the pipe path to the ground.

Bacterial corrosion may occur when pipe-line growths die and in decomposing form hydrogen sulfide in contact with iron. Some organisms form hydrogen sulfide directly from dissolved sulfates in the absence of oxygen.

**Factors in Pipe-Line Corrosion.** Following is an enumeration of factors which influence the corrosion behavior of water supplies. Chemical, physical, and biological properties all play roles of varying importance in determining the net rate of corrosion.

1. *Dissolved Oxygen.* This factor is unquestionably the most important single cause of corrosion, the rate of attack varying with the oxygen concentration. An intimate relation is evident since the final result of corrosion is the conversion of iron metal into its various oxides. Many instances are known where aeration of well supplies to remove carbon dioxide and iron causes a corrosive condition by saturating the water with oxygen. Tests on aerators show them to be much more efficient oxygenating devices than they are carbon dioxide strippers. Since the solubility of oxygen increases as the temperature is lowered, some surface supplies may cause more numerous complaints due to corrosion in winter.

2. *Carbon Dioxide.* This gas, being a weak acid in solution, has a feeble corrosive action on iron; however, its importance in governing the rate of corrosion depends principally upon its influence on the nature of the corrosion products. The main effect of carbon dioxide is embraced in its relationship to the alkalinity and calcium hardness. Above a certain limit carbon dioxide will destroy a protective film of calcium carbonate.

3. *Protective Films.* The character of the surface film is of utmost importance in determining the falling off in rate of corrosion after attack on the originally clean surface. Such films may be applied to pipe before installation or even obtained to a small degree from the low-grade shielding action of the rust itself. The action of paints, coatings and pipe scale is

essentially the separation of the metal from the oxygen-containing water. Some acid swamp waters form a protective film of organic matter.

4. *pH, Alkalinity, Calcium and Total Solids.* These analytical quantities are significant in their relationship to the formation and maintenance of a protective calcium carbonate scale in pipe. The amount of total solids present exerts only a minor influence in the pH range of potable waters. Low pH values permit corrosion to continue by preventing the deposition of carbonate scale. High alkalinity and calcium content promote the formation of a protective calcium carbonate scale. In bare pipes, incipient rusting always starts, but in non-corrosive waters under conditions shown later, calcium carbonate is deposited in the rust structure, filling its pores and waterproofing the metal. If rusting is arrested, later deposits then become carbonate-type films. Residual turbidity particles that have passed through the filters form a part of the carbonate coating.

5. *Temperature.* This factor exerts an important influence through several conflicting effects. As previously mentioned, an increase in water temperature lowers the solubility of oxygen and, therefore, the rate of corrosion should decrease as water is warmed. However, an increase in temperature speeds up the corrosion reactions and the rate of diffusion of oxygen through surface deposits, roughly doubling the rate for every rise of 18°F. The net effect of increased temperature then is determined by the relative magnitudes of each separate tendency. Actually, the effect of lowered oxygen solubility overtakes the effect of increased reaction rate in an open tank at about 154°F. Below this point, rising temperature increases corrosive action, but above this figure, rate of corrosion decreases due to diminished oxygen supply.

More influential yet is the effect of temperature on the protection afforded by calcium carbonate scale. High temperature strongly promotes the deposition of carbonate scale and in that way hot-water lines obtain considerably greater protection

than cold-water piping. Where film protection has been achieved, the other effects of change in temperature are made inoperative.

6. *Presence of Inhibitors.* Inhibitors may retard or even prevent corrosion. These are substances which are held as an exceedingly thin film on the metal surface and interfere with the attraction of the metal for the dissolved oxygen. Their action may be considered as a special type of protective film.

7. *Velocity of Flow.* In a corroding pipe, the velocity of the water acts in two ways. The first effect is to increase the amount of oxygen contacting the metal surface during a given time; the other effect is to create turbulence which further facilitates intimate contact by oxygen and also interferes with the adherence of a protective layer. As the rate of flow passes from the linear to the eddying type, the rate of corrosion is sharply increased. In feeders and mains, the character of flow is always turbulent; in service lines and fixtures, the flow may be of either type.

8. *Nature of Metal.* Rate of corrosion depends naturally upon the kind of metal used; differences are noted even within the same type. Thus among the ferrous metals, wrought iron is more rust-resistant than cast iron, and both are much superior to ordinary steel. Sand-cast iron pipe is claimed to owe its rust-resistance to the presence of a thin skin of silica-iron composition, which forms where the molten metal contacts the sand mold. Cast iron, when destroyed by soil corrosion or by stray electric currents, retains its shape as a graphite core of appreciable strength.

Among the brasses, red brass, high in copper, is superior in corrosion resistance to the yellow high-zinc variety. Slightly alkaline scale-forming waters which ordinarily do not affect iron piping embrittle brass by selectively removing the zinc from the alloy. Copper and lead are both subject to corrosion in slightly acid waters.

9. *Bacterial Corrosion.* Reference has already been made

to the corrosion caused by formation of hydrogen sulfide by bacterial colonies. This factor is encountered only in unsterilized supplies or where the chlorine residual does not persist through the entire system.

**Methods of Control.** Corrosion control is based on a proper recognition and manipulation of the factors which influence the rate of corrosion. Obviously some of the important factors, such as temperature and presence of dissolved oxygen, are not subject to control in municipal supplies. In a few very special cases for industrial supplies, dissolved oxygen is greatly reduced by spraying water under vacuum in a tower and removing the final traces with sodium sulfite.

Choice of pipe-line materials allows the substitution of asbestos-cement composition for iron mains, but this change does not stop corrosion in the consumers' plumbing. For service connections, copper, brass, lead, and tubeloy, a lead composition, are ordinarily available. Plastic pipes also are being exploited.

Protective coatings provide a satisfactory means of combating corrosion. Manually applied coatings consists of coal tar dips or cement linings. Coal tar coatings are somewhat rust resistant, but in a markedly corrosive water there still will be no relief from rusting. Cement linings in  $\frac{3}{4}$ " and larger pipes present more substantial resistance but even here a corrosive water leaches the cement material. In certain soft water sections, as in the Eastern States, no new cast iron pipe is laid without being cement-lined. By means of the Tate process, pipes down to 2" diameter may be cement-lined in place. A combination of cement lining painted over with a sealing coat of so-called bitumastic enamel or a bentonite type of asphalt emulsion is the best manually applied protection. The latter coating may be spread on wet surfaces. Such pipes are quite corrosion-resistant and preserve their low friction characteristics for years. It is evident that these linings do not protect the consumers' plumbing. Their best service is in carrying untreated corrosive waters from a source to a treating plant.



**Carbonate Coatings.** Protective coating, formed from scale precipitated out from solution in the water itself, is an effective shield against corrosion. As such a scale consists principally of calcium carbonate, conditions favoring its deposition are those that reduce the solubility of this material. Waters that have been softened by lime to remove so-called bicarbonate hardness form a calcium carbonate type of scale as a result of the softening reaction; after filtration, the water is left supersaturated with calcium carbonate, and slow precipitation of this material continues in the pipe-lines and forms a protective film. Untreated water, when soft or of low alkalinity, will form carbonate scale when the pH, calcium, and alkalinity are raised sufficiently by means of alkali.

The accompanying diagram, Figure 28, which is based on the Langelier formula, predicts whether or not a water is able to deposit a carbonate coating. A coating will form only if the alkalinity and calcium content bear a certain relationship at a given temperature. The total amount of dissolved solids present also affects this relation in a minor way. Directions for the use of this chart are printed as part of the figure. The scales allow calculation of the pH which a water of prevailing alkalinity and calcium concentration must have in order to be in balance or at equilibrium. Such a pH value with a subscript s ( $\text{pH}_s$ ) denotes the pH at saturation. At this point, the water will not attack a previously laid scale and so it is non-corrosive. If the actual pH of a water is 0.5 or more below  $\text{pH}_s$ , the water will be definitely corrosive. Many well waters fall in this category. Similarly, if the pH observed in the water sample exceeds  $\text{pH}_s$  by a few tenths, an adherent scale of calcium carbonate will be deposited.

In order to calculate  $\text{pH}_s$  by means of Figure 26, the necessary data are readily obtained. Tests for pH and for alkalinity are commonly run for plant control, the temperature is fairly well fixed, and the residue on evaporation is of such small relative importance that large fluctuations have only slight

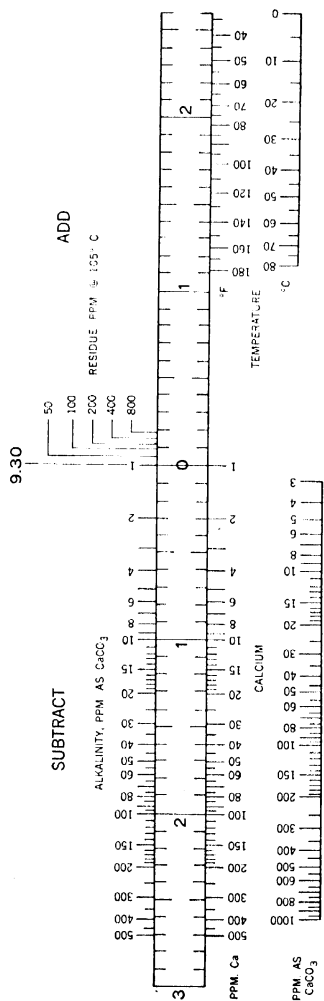


FIGURE 28

### Diagram for pH of Calcium Carbonate Saturation Langelier

Formula: Larson-Buswell Residue-Temperature Adjustments

Directions: To 9.30 add the sum of the scale values opposite the residue and the temperature figures. From this subtract the sum of the scale values corresponding to the calcium and the alkalinity.

Example: Given Ca = 10 p.p.m., Alkalinity = 50 p.p.m. as CaCO<sub>3</sub>, Temperature = 80°F., Residue = 200 p.p.m.; find pH.

Solution:  $pH = 9.30 + (0.11 + 1.96) - (1.00 + 1.71) = 8.66$ .

Significance:  $pH < pH_s$ , undersaturated; corrosive tendency  
 $pH = pH_s$ , stable  
 $pH > pH_s$ , supersaturated; scale-forming tendency

(Courtesy of the American Water Works Association)

effect. Once this last value is determined, reasonable differences in total solids may be neglected. The amount of calcium present is easily and quickly determined by means of a selective soap titration. All of these analytical methods are presented in Chapter 19.

Another related value, the Ryznar stability index, is given by the expression ( $2 \text{ pH}_s - \text{pH}$ ). Numerical values above 7 are indicative of corrosion; values below 6 are associated with scaling type waters.

**pH Control.** Corrosive waters are conditioned commonly by raising their pH. With hard or with moderately soft alkaline waters, high in carbon dioxide, removal of a portion of the carbon dioxide may suffice. Waters low in calcium require direct addition of lime or passage through limestone contact beds to increase the amount of calcium present. The latter treatment, where applicable, needs no control but requires an extensive volume of limestone bed sufficient for about three hours contact. Fairly hard waters, low in alkalinity and in carbon dioxide either naturally or after aeration for iron removal, are best treated by sodium carbonate, sold as soda ash. This chemical supplies the carbonate required for scale formation. Its use is advisable when further increase in hardness by treatment is undesirable. For very soft waters low in carbon dioxide and in alkalinity, both lime and soda ash should be added. Where only a very slight increase in pH is needed, caustic soda may be used if added with proper regulation.

Whatever chemical treatment is selected, the pH of the conditioned water should approximately equal the  $\text{pH}_s$  value as obtained from Figure 28. By raising it about 0.5 above this value, the deposition of scale on new lines may be hastened. Observation of the progress of scale deposition may be noted by installing test nipples on frequently used water lines in the plant and out in the system. When the scale coverage has become perceptible, the pH of the water may be lowered until the balanced or a slightly lower value of  $\text{pH}_s$  is obtained. In a

properly functioning system, about 0.2 units below the pH<sub>s</sub> value is desirable in order to keep scale formation in hot water lines as low as possible while still securing protection of cold-water pipes.

**Marble Test.** A direct and simple indication of the condition of a water sample with respect to its under or oversaturation with calcium carbonate is provided by the von Heyer "marble test." Details of this test, also termed the carbonate stability test, are given in Chapter 19. Its essential steps consist in shaking a sample of water in a bottle containing pure calcium carbonate powder for a period of from 10 minutes to about 8 hours, then settling the mixture and carefully pipetting off a sample of the clear liquid which is more or less completely saturated with calcium carbonate. Its pH and corresponding alkalinity is tested and compared with the original value. The change in alkalinity is ordinarily the more sensitive indication. If either of these quantities increase, it would be as a result of attacking and dissolving some of the calcium carbonate which would show that the original water sample was undersaturated and, therefore, likely to be corrosive. However, if the pH and the corresponding alkalinity dropped, a deposition of calcium carbonate has occurred, and the water being able to lay down a scale of this material will be non-corrosive. A balanced water by this test would neither dissolve nor release calcium carbonate. This test may be run continuously by allowing the water sample to flow slowly through a five-foot glass tubing packed with calcium carbonate.

**Amount of Alkali.** The amount of alkali required to make a corrosive water attain balance may be found by any of three currently available methods as described presently. The first method is a simple direct jar test with formation of a visible scale once the correct dose is exceeded; the second resembles the first method but "marble tests" are run on the treatment products to determine the state of balance; the third method is less direct in that a dose is adopted where the pH of the treated

samples agree with the calculated  $\text{pH}_s$  as obtained theoretically. Assuming the required lime dosage is to be found, the steps in each method are as follows:

a. *Langelier's Direct Method.* Set up a series of water samples in 100 ml. graduate cylinders or Nessler tubes. Dose each with increasing amounts of lime solution (1 gram/liter) to give treatments of 0 to 50 p.p.m. by 5 p.p.m. intervals. One ml. of lime solution is equivalent to 10 p.p.m. treatment if 100 ml. sample volume is taken. Shake each tube occasionally for about half an hour, settle overnight and observe the lowest dose which produces a visible sediment. This dosage approximately is the lime required to form a protective scale. A closer value may be found by repeating the test with smaller differences between the doses in the vicinity of the first amount producing a sediment.

b. *McLaughlin's "Marble Test" Graph.* Set up a series of liter or gallon samples in a stirring machine. Dose each with

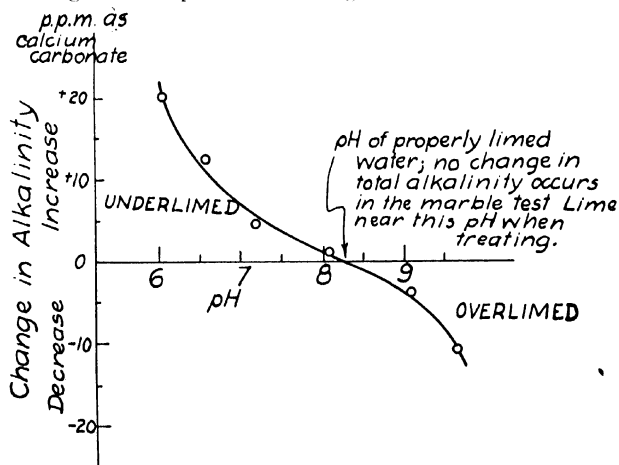


FIGURE 29

Plot of McLaughlin's Method for Determining the Lime Dosage Needed to Control Corrosion

increasing amounts of lime solution, as above to cover the whole range of probable treatment. Stir one-half hour and settle four hours. Run marble tests on each product and plot the change in alkalinity against the corresponding pH value. Such a plot is shown in the Figure 29. The point of zero alkalinity change i.e., where the curve crosses the horizontal axis, marks the pH to which the water should be raised by lime treatment.

c. *Moore's Method.* A series of samples are treated with increasing lime doses, as in the previous methods, and after about one-half hour's contact their pH is determined. Corresponding to each dose, the value of the saturation pH is found using the diagram, Figure 28. Addition of lime is allowed for

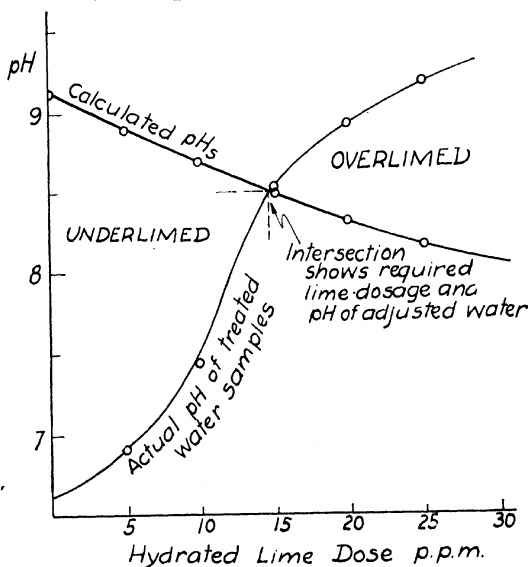


FIGURE 30

Plot of Moore's Method for Determining the Lime Dosage Needed to Control Corrosion

by adding 1.35 p.p.m. as  $\text{CaCO}_3$  to the original alkalinity and 0.54 p.p.m. to the calcium content for each 1 p.p.m. of hydrated lime treatment. Two curves are plotted, one is the actual pH of treated samples against the lime dose and the other is the calculated  $\text{pH}_s$  for each lime dose. Obviously where the curves cross, as in Figure 30, the pH equals  $\text{pH}_s$ , and hence this point marks the lime treatment required for saturation.

**Corrosion Inhibitors.** Whereas a wide variety of materials, when present in negligible amounts, can impede corrosion of iron, only two such compounds have found extensive application in potable waters. These are sodium silicate and Calgon (sodium hexametaphosphate). Sodium heptaphosphate and tetrasodium pyrophosphate also give anti-corrosion protection. Organic materials now being exploited as inhibitors are expensive; in the presence of free chlorine their efficiency is impaired. Protection seems to be afforded by a non-permanent surface film deposited over the metal, because protection is gradually lost if the inhibitor is discontinued. These materials, in effect, treat the metal surfaces. Inhibitors are best fed into the plant effluent.

*Sodium Silicate.* When using sodium silicate, an initial dose of about 8 p.p.m. of soluble silica is fed to build up a film, said to be ferrous silicate, on the pipe walls. Larger amounts are avoided so that old rust particles are not detached to form red water. Once the protective film is formed, the dosage is tapered down to 4 p.p.m. of soluble silica; 2 p.p.m. has been found too low for full protection. This chemical generally provides adequate protection at low cost. Many natural waters contain much more silica in various forms of combination.

*Sodium Hexametaphosphate.* By plating out a stable surface film, sodium hexametaphosphate stops general corrosion inside iron pipes, the cause of red water, throughout the pH range 5.2 to 10.0. When using hexametaphosphate in soft acid waters, it may be advisable to raise the pH by adding alkali, although some investigators prefer a low pH to combat the tendency toward localized corrosion which forms tubercles. A

good measure of protection is also given to zinc, aluminum, brass, bronze and copper fittings. Practical doses reduce the solution of lead from new and used lead services when below pH 7.0; above pH 8.0, a slight but unimportant increase is initially noted in the lead pick-up but this effect vanishes with continued usage.

Tuberculation which is already present retards the production of a protective film over the metal by retaining some of the hexametaphosphate. Therefore, to restore full flow capacity on badly corroded systems that are not mechanically cleaned, a somewhat higher dosage is required. Only in scattered instances are the old deposits sloughed off, and these are cases of deposits from iron and manganese already present in the water. The debris is flushed out.

Dosage depends on the surface area of piping relative to pumpage, therefore, the size of the system is an important factor in determining the feed. Very roughly, a system supplying less than 0.5 million gallons a day (MGD) would require around 4 p.p.m. hexametaphosphate to prevent red water; a 1 MGD supply would take about 2 p.p.m.; and a 10 MGD flow only 0.5 to 1 p.p.m. A relatively high rate of feed, at least double these figures, is applied when starting off the treatment. This high dose is reduced, as metaphosphate shows by test to be at the extremities of the system. A minimum of 0.2 to 0.5 p.p.m. should be maintained at all points. At dead ends, bleeders should be provided to pass a sufficient supply of treated water to build up a film. Metaphosphate is fed in solution. As the strong stock solution is corrosive, this tendency is controlled by raising its pH above 9.0 with 10% soda ash or 3% caustic soda. Since bacteria thrive in phosphate solutions, addition of enough chlorine to maintain a slight residual in the stock solution will prevent high bacterial counts from this source.

Metaphosphates are also used in conjunction with protection against calcium carbonate scale. Low doses interfere with the crystal formation within the scale. As a result, the scale, if formed, is more evenly extended throughout the distribution



system rather than bulked near the treatment point. Typical dosage of metaphosphate to control deposition lies in the range from 0.25 to 0.50 p.p.m.

Metaphosphate prevents tuberculation and incrustation in hot water piping also. For domestic services, a slowly soluble type of crystals is fed from a pot type feeder to protect both hot and cold water lines. A riser pipe, having a plug for renewing the charge at the top and a valve to regulate rate of leaching at the bottom T connection, in the water line to a heater gives satisfactory feed. About four ounces per month is usually sufficient in the average home.

**Chlorination.** Corrosion caused by bacteria may proceed in a water which has received other anti-corrosion treatment. Dead ends are especially subject to attack. Obviously the causative organism must be killed. Chlorine is effective especially above break-point doses; satisfactory control is also afforded by chloramines. Both disinfectants, being stable, penetrate through the pipe network and on killing the bacteria detach them in large masses. These black masses pass through consumers' taps causing temporary complaints. A flushing program should be carried out to purge the lines. After these growths are eliminated, the dosage may be substantially reduced to give the usual 0.2 p.p.m. residual.

**Cathodic Protection.** When pipe-lines are destroyed by stray current electrolysis, the metal at the point where the current leaves the pipe-line always shows a small but measurable positive voltage above that of the soil. It is because of this voltage that the current jumps from the pipe-line and causes pitting. Therefore, when the voltage difference between the soil and the pipe metal is eliminated, stray current corrosion should cease. Furthermore, when the pipe-line is given a negative potential relative to the ground, all outside corrosion should stop. A method based on these principles is known as cathodic protection.

In cathodic protection of a pipe-line, piles of junk metal are

buried at intervals along the route and are connected to the positive pole of a rectifier while the pipe is connected to the negative pole. Copper oxide or selenium plate rectifiers are generally used; the latter material provides long life with electrical efficiency ranging between 60 to 70%. Protective provision must be made for other nearby metallic structures, otherwise severe damage may be inflicted on them. The pipe also should have an insulating wrapping; otherwise current loss becomes uneconomical.

The same principle and type of charging equipment is used in the cathodic protection of the inside of water tanks. Carbon rods or stainless steel wires, connected in parallel, are suspended from insulators in the water to form positive electrodes; a two- or three-volt negative potential is maintained on the tank plates. An electrodeless system is the latest development in this field. The tank is thus prevented from rusting below the water line. A coat of good preservative paint is applied over the exposed steel above the water level. No coating is needed below the water level; all old paint and rust is shed off by this process to leave a powdery-gray covering over the bright metal underneath.

**Tests.** In surveying a water system for corrosion studies or in maintaining protective treatment, the following tests, most of which are already usual plant routine, will be found helpful.

a. *Dissolved oxygen.* Tests are run on samples at the pumping station and at various points in the distribution system. A drop in dissolved oxygen content, as the water advances in the grid, indicates its removal to form rust.

b. *Iron.* Increase in dissolved iron in the system and at dead ends indicates that corrosion is occurring.

c. *pH and alkalinity.* As the iron rusts or during the solution of protective carbonate scale, both pH and alkalinity will increase.

d. *Marble slab.* A white marble slab placed underneath a drip cock will be stained if corrosion has occurred in the piping.

e. *Marble test.* Corrosive waters increase considerably in pH and alkalinity when run by this test. Samples taken along a corroding system show decreasing gains after testing.

In addition to the determinations mentioned, the diagram, Figure 28, is useful in predicting the corrosion tendency of a water sample. Jar tests have also been described to determine correct dosages of alkali. Test nipples placed for easy removal are useful indicators. Periodical friction tests of important mains furnish a sensitive index to the progress of corrosion or its correction.

## CHAPTER 13

### TASTE AND ODOR REMOVAL

PRESENCE of foreign tastes or odors in a water supply usually provokes the most serious complaint that consumers are likely to make. Objectionable tastes cause widespread criticism because every user is necessarily affected. The memory of an undesirable taste commonly leads consumers to forget all other characteristics when describing a supply. Only rarely do tastes imply a sanitary hazard except that consumers may substitute better tasting but unsafe supplies.

**Causes.** Tastes and odors are caused by :

1. Minerals, such as common salt (sodium chloride), high sodium alkalinity, Epsom salt (magnesium sulfate), dissolved iron, caustic alkalinity and high mineral content.
2. Dissolved gases, such as hydrogen sulfide, natural gas (methane), and excess chlorine.
3. Earthy substances.
4. Decayed vegetation.
5. Industrial wastes and their chlorination products.
6. Plankton, as defined later.

Mineral tastes are generally unobjectionable unless too pronounced. Above a concentration of 325 to 400 p.p.m., sodium chloride produces a brackish taste. This condition occurs in some deep-well waters and in surface supplies subject to seawater underflow. High sodium alkalinity causes a soda taste in some ground waters. Neither of these compounds can be removed economically from municipal supplies although industries remove these substances by means of synthetic resins. Carbonaceous zeolites are especially advantageous for removal of soda alkalinity. High mineral content, Epsom salts, and

dissolved iron in ground waters give characteristic tastes; their reduction is effected by some type of lime softening and iron removal. Dissolved iron also supports certain higher bacteria which produce odors of decomposition upon dying. Caustic alkalinity results from over-treatment with lime; water in this condition loses some of its thirst-quenching properties. Reduced lime dosage, recarbonation, acidification by mineral acids, or blending with untreated water are used to prevent causticity in the water delivered from a softening plant.

Dissolved gases are removable by aeration, as discussed in Chapter 6. Hydrogen sulfide is also removed by chlorination. When excess chlorine persists after aeration, it is reduced by lengthening the period of contact or by some dechlorinating agent. Sunlight dissipates chlorine rapidly in open reservoirs.

Earthy tastes are encountered in waters stored in new, unlined reservoirs. Stagnant tastes also are carried by the bottom water of deep reservoirs as they rise to the surface during a seasonal overturn. Obviously, intakes should be placed at several levels of a deep reservoir to allow selection.

Tastes caused by decayed vegetation are met in surface supplies taken from a swampy watershed. Elimination of this taste is possible by the procedures discussed later. Rooted aquatic vegetation growing in depths over 10 feet do not cause taste but may provide an anchorage for large colonies of algae.

Industrial wastes impart tastes to a surface water more or less characteristic of the source. Wastes from coal tar and related industries contain phenols which intensify tastes when the water is chlorinated. Wastes of industrial origin are partially controllable by a pollution-abatement program. Reduction of tastes resulting from wastes require various treatments as described later.

**Algae.** Plankton is a general term which includes all minute living forms whose natural habitat is in surface waters. This term embraces higher bacteria, algae, protozoa and crustacea; frequently the word algae is used to cover all these classifica-

tions. Micro-organisms produce taste mainly on decomposition after death. Certain algae contain oil globules inside their cell walls; following death these strongly scented oils are released in the water thus intensifying the tastes. Therefore, an increase in taste always results for a short while after applying treatment for their destruction. Two aspects of micro-organism control must be considered: first, their elimination from the water, and second, the removal of tastes and odors from the water.

Well waters occasionally contain algae of obscure origin, presumably introduced through carelessness during construction. Higher bacteria, including the iron bacteria *crenothrix*, grow in the dark, and, therefore, can thrive inside pipe-lines. These growths are stopped by removing their food supply, such as iron or organic matter; by aeration, to keep the dissolved oxygen at a level slightly above 2 p.p.m.; by feeding about 0.5 to 3.0 p.p.m. of copper sulfate into the system for several weeks; or, by maintaining a residual chlorine content between 0.5 and 1 p.p.m. with the use of ammonia to stabilize the residual.

Algae are simple plant forms, somewhat more complex than bacteria. Some light sensitive pigment, either green, blue-green, or brownish, in their cell fluid enables them to utilize dissolved carbon dioxide as a food when exposed to sunlight. Most of the species require sunlight to grow but some will persist even in the shade. The greatest numbers are found in shallow waters but some varieties, like diatoms sink to the bottom of deep reservoirs. Strong sunlight, low turbidity to permit light penetration, warm temperatures, high alkalinity, and high carbon dioxide content favor their multiplication. Algae are the most common source of foreign tastes and odors in surface supplies or in open reservoirs. These tastes vary with the causative species, and may resemble those of green leaves, flowers, aromatic oils, fish, and odors of decomposition. Other objections to their presence are their unsightly appearance when

growing in large colonies and their clogging action on filters.

Protozoa are single-celled animals that occupy somewhat the same position in the animal world as bacteria occupy among plants. As animals, they require soluble organic matter for food. They thrive after algae are killed and decompose. They are also present in large numbers downstream from points where sewage is added to a flowing stream. Crustacea are minute shellfish which resemble the larger forms of this family. Their main offense is the clogging of filters following an algae infestation.

**Algae Control.** Elimination of algae from surfaces of aerators, discussed in Chapter 6, is most readily accomplished by providing a canopy to shade the structure. A copper sulfate whitewash technique, described in Chapters 7 and 8, gives excellent results in checking algae growth attached on the upper portions of submerged walls in open reservoirs at treatment plants. Reservoirs for storing treated water should be covered both to prevent the growth of algae and to minimize the entry of air-borne contamination.

**Copper Sulfate.** Algae control in raw water reservoirs is based mainly on the remarkable killing action of copper sulfate when applied in small doses. The amount of copper sulfate (blue vitriol) to be used depends upon the species of micro-organism which must be eliminated. It is always desirable to identify and count the different algae present in representative samples from various parts of the reservoir. The lethal dose for each principal organism is then read from tables and a quantity of copper sulfate applied, corresponding to the more resistant types, but not exceeding a concentration that is fatal to fish. Abbreviated tables are given here, but usually a more extensive list in standard textbooks should be consulted.

It will be noted that the lethal concentration for micro-organisms varies from about 0.1 p.p.m. to 10 p.p.m. and over. Toxicity to fish begins around 0.15 p.p.m. in very soft waters. Small crustacea are resistant to copper sulfate treatments. Due to the precipitation and loss of copper from alkaline waters, a

TABLE 8  
Copper Sulfate Dosage Necessary to Kill  
Certain Micro-Organisms

| Species    | Class            | Dose      |                         |
|------------|------------------|-----------|-------------------------|
|            |                  | p.p.m.    | lb. per million gallons |
| Synedra    | Diatom           | 0.36-0.50 | 3.0-4.2                 |
| Eudorina   | Green Algae      | 10.00     | 83.0                    |
| Spirogyra  | Green Algae      | 0.12      | 1.0                     |
| Anabaena   | Blue Green Algae | 0.12      | 1.0                     |
| Euglena    | Protozoa         | 0.50      | 4.2                     |
| Synura     | Protozoa         | 0.12-0.25 | 1.0-2.1                 |
| Daphnia    | Crustacea        | 2.0       | 16.6                    |
| Crenothrix | Higher Bacteria  | 0.33-0.5  | 2.8-4.2                 |
| Beggiatoa  | Higher Bacteria  | 5.00      | 1.5                     |

TABLE 9  
Copper Sulfate Dosage Safe for Fish \*

| Species    | Safe Dose |                         |
|------------|-----------|-------------------------|
|            | p.p.m.    | lb. per million gallons |
| Trout      | 0.14      | 1.2                     |
| Catfish    | 0.30      | 2.5                     |
| Suckers    | 0.30      | 2.5                     |
| Goldfish   | 0.48      | 4.0                     |
| Perch      | 0.72      | 6.0                     |
| Black Bass | 2.1       | 17.0                    |

\* These doses may be greatly exceeded in highly alkaline and hard waters.

higher dose up to about 2.5 p.p.m. and over usually is safe for fish when employed under proper control. Where fish conservation is not a factor or where water is very hard or treated later with lime or coagulant, a much higher starting dosage may be adopted. A reduction of 2% from the tabulated figures is made for each degree above 50°F.; an increase is applied for each degree below this temperature. Later doses may be adjusted downward if results of the first application are successful. The pH value of the water should also be considered in closer adjustment of dosage. The volume of a reservoir in million



gallons is equal approximately to the surface in acres multiplied by the depths in yards.

In a prudently managed reservoir, copper sulfate is applied before heavy algae reproduction starts. During the early spring, following a week of bright sunny days, a small preventive dose should be distributed over a large portion of the reservoir to arrest the initial development of micro-organisms. Later, during the warm season, the applications are repeated at monthly intervals.

Copper sulfate may be applied to a reservoir from a skiff or motorboat by the following methods:

1. Sacks or perforated cans, one hung on each side of a boat are dragged through the reservoir while traveling in lanes about twenty-five feet wide, criss-crossing the area. Exposure may be kept constant by attaching burlap bags to a frame on either side of the boat and filling them with additional chemical as required. This method has the advantage of simplicity.

2. A barrel or tank containing copper sulfate solution discharges overboard at the stern so that the propeller causes mixing. A pump may be employed to discharge the solution through perforated pipes covering a thirty-foot strip.

3. A powder is blown from a feed table by a fan. The dust settles on the surface and dissolves in the upper layers where algae are most numerous. This method is the most economical for large scale operations.

4. A solution is sprayed over the surface of the reservoir.

To treat a small reservoir conveniently, a sack of crystals may be submerged at the inlet. Continuous application of copper sulfate prevents the appearance of algae.

Copper sulfate is practically without effect on higher aquatic vegetation and pond weeds.

**Chlorination of Reservoirs.** In treatment plants, prechlorination greatly reduces the amount of algae growing on the filters. Similar to treatment with copper sulfate, chlorine or its compounds also may be used to control certain species of algae

in open reservoirs. Doses between 0.5 to 1.0 p.p.m. kill most micro-organisms, but this concentration is absorbed by organic matter quickly in sunlight, unless fixed by adding ammonia. Continuous chloramination is an effective preventive against algae growth.

Occasionally, the combination of copper sulfate, chlorine and ammonia is used to combat certain organisms resistant to each chemical if used separately. This method is known as cupri-chloramination.

**Activated Carbon.** Through its power to prevent penetration of sunlight appreciably below the surface when dispersed in treatment basins, activated carbon is used to suppress the growth of algae. A suspension of the powder is discharged at the entrance or baffle of a reservoir where turbulence provides a good mix with the water. This method, known as the "carbon blackout," takes a dosage of about 2 p.p.m. A carbon blackout may be produced conveniently in a small basin by submerging a charge of activated carbon in a burlap bag, and agitating this sack violently, by jerking a drawstring, several times on a sunny day. By means of a portable ejector operated from a boat engine, carbon may also be used to blackout impounding reservoirs. The dosage is about 0.3 lb. per 1,000 sq. ft., distributed on sunny days.

Activated carbon, in doses usually ranging from 5 to 50 p.p.m., is also spread in impounding reservoirs to reduce the odors resulting from the application of copper sulfate. As copper sulfate has a coagulating effect on the carbon particles, the carbon is applied on the day after the copper sulfate treatment.

**Measurement of Odor.** In order to deal systematically with taste and odor conditions in a water supply, some means for measuring their intensity is needed. Odors rather than tastes are used in these tests because of the close relation of taste to odor, the quick fatigue experienced when critically tasting a series of samples, and the sanitary advantage when dealing

with unpleasant waters. Odors are sniffed preferably from a half-filled wide-mouth glass-stoppered flask after first shaking the sample to saturate the air space with the volatile odor. Two procedures for measuring the intensity of the odor are possible: in one, the air above the sample is diluted with varied amounts of normal air in a special sniffing device, in the other, a series of dilutions with odor-free water are prepared and sniffed. A glass nosepiece may be used, if desired, to withdraw air near the surface of the sample. The water dilution method is generally favored. Further details of this procedure are given in Chapter 19.

It is obvious that the greater the concentration of odor-producing substances in a water, the more the sample may be diluted with odor-free water before an observer loses recognition of the odor. The *threshold number* may be defined as the number of times a sample may be diluted and still give a positive odor when compared with a blank of odor-free water. Dilutions are best made in an orderly scheme as explained in Chapter 19. By making the threshold rest at elevated temperature, usually 140°F., odors are intensified. Thus by a hot test, an operator can detect a developing odor condition and apply remedial treatment before consumers start to complain. A statement completely describing the odor characteristics of a sample should include a descriptive note stating the kind of odor, or comparison with familiar odors; and the threshold numbers, both cold and hot. These data are essential for adequate and economical odor-reduction treatment.

The odor intensity at which the public complains varies with the community and its previous experiences with tastes in the supply. Some localities accept a threshold number of 3, in other places a value of less than 10 is satisfactory. Above these values some odor-reducing treatment is needed. In a perfect water, the cold threshold number is zero, and the hot threshold does not exceed 2.

## METHODS OF ODOR REDUCTION

Odor-control treatments are based on feeding one or more of the following chemicals to the water: activated carbon, chlorine above break-point doses, chloramines, chlorine dioxide, clay, ozone, and potassium permanganate. Aeration will remove volatile gases, such as hydrogen sulfide, natural gas, and reduce the less objectionable carbon dioxide but odors due to algae and trade wastes are hardly affected. Nevertheless recent reports indicate that if aeration is performed with high pressure behind an efficient spray nozzle, very material reductions in odor may be achieved in waters containing certain chemical trade wastes. Further odor reduction to acceptable limits may then follow by supplementary measures. Coagulation and filtration incidentally reduce odors somewhat but are not a substitute for the recognized odor-control measures when these are required.

**Activated Carbon.** Activated carbon may be considered as a form of charcoal which has received special processing by superheated steam, hot air, or chlorine, to clean out and open up sub-microscopic pores. In this way, an enormous surface area is exposed when grains of this material are submerged under water. In accordance with certain physical laws the organic impurities, like oils and waste products, tend to gather on the surfaces and the pores of the activated carbon. This action is termed *adsorption*, to distinguish it from the simple case of absorption, which is involved in drying ink with a blotting paper. Adsorption is highly selective; some impurities are much more readily removed from solution by activated carbon than others. Charcoal possesses a slight adsorptive capacity; this property formed the basis for the old custom of placing a stick of the material in drinking water containers. By the process of activation, this power is increased roughly a hundredfold. Activated carbon is used for water treatment in the form of a fine powder and as large granules.

**Powdered Activated Carbon.** *Points of Application.* Powdered carbon is ground finely, about 99% passing through a 200 mesh sieve, so that in use its rate of settling will be slow and contact with the water correspondingly prolonged. Depending upon the intensity of the odor, its frequency of occurrence and the design of the plant, the point of application may be (a) before sedimentation, (b) to the settled water and (c) directly on the filters. A split treatment involving carbon feed at more than one point is frequently used to take advantage of the fact that adsorption is more efficient in stages.

For only occasional occurrence of mild odors, requiring no greater than about 10 p.p.m. dosage, application of a suspension or a slurry, or even carefully distributing the dried powder and paddling to effect mixture directly on the filter surface has the advantage of giving most prompt improvement in the plant effluent. Some operators regard this method as offering the greatest effectiveness per pound of carbon used. In this way the regular plant coagulation and sedimentation are allowed to decrease the odor somewhat and carbon is not wasted by being dropped down into the sludge. Filter runs are not materially shortened at this dosage but some carbon may pass through the filter bed depending on the sand size. A new carbon mat must be applied following each wash. When odors require more carbon, the filter treatment may still be retained, with additional application, as needed, to the reservoirs or mixing tanks. When the odor is continuous, a feed into the mixing chamber is a more convenient treatment.

When applied to the settling reservoir effluent, a certain amount of desirable mixing and contact is afforded in the settled water passages; a large portion of the carbon is carried to the filters and deposited with floc in the mat. This plan is useful for mild tastes and odors, especially when intermittent in occurrence.

When odors are pronounced and of regular occurrence, carbon is applied in the mixing basin. Some point following the

formation of floc is preferable so that the carbon particles are left exposed. A contact period is provided equal to the time in the mixing basin plus that part of the retention time in the sedimentation reservoir during which the carbon is still suspended. There is no upper limit to the amount of carbon which can be added here; dosages have ranged from 1 to 1,200 p.p.m. Incidental benefits of carbon at this point are improved coagulation, enabling a slight reduction in the coagulant dosage; and a stabilizing effect on odor production within the settled sludge.

Powdered activated carbon may be fed by means of either solution or dry feed equipment. With wet feed apparatus the carbon must be kept uniformly suspended in the stock tank by means of agitators, compressed air, or by a small recirculation pump. If an orifice is used, it should be made of glass or non-corrosive material, and examined regularly. In dry feed machines, carbon tends to arch in the hopper. This difficulty may be prevented by choosing a hopper with one side vertical, or by providing an agitator or vibrator for the ordinary tapered hopper. In the solution box, water sprays or some type of agitation should be provided to wet the carbon and mix it thoroughly. The suspension is best carried to the point of application through a water ejector, or otherwise well diluted.

In storing activated carbon the air should be free from chlorine or gasoline vapors as these materials reduce efficiency of adsorption. To avoid risk of fire, choose locations safe from high heat, flames or sparks. If carbon catches on fire extinguish it with a fine spray of water or a foam type extinguisher to prevent scattering the burning particles, otherwise the fire should be allowed to smoulder out quietly. When handling bags of activated carbon, the spread of black dust over structures and equipment may be eliminated by emptying the packages in a snugly fitting discharge box in the bottom of which is built a traveling knife blade operated from the outside.

*Dosage Requirements.* The amount of carbon required to reduce an odor down to an unobjectionable level depends upon

the particular odor, its intensity, plant characteristics, and the quality of the carbon employed. For any particular odor situation, the dosage should be determined by running a series of jar tests using a wide range of trial doses, and allowing a mixing time, as shown by experience, to be equivalent to that found in the plant. The dose that reduces the odor sufficiently is selected. For best control a threshold odor test should be run on each treatment and the results plotted on a graph, comparing dosage and threshold odor; from it the dosage needed for any desired odor improvement may be read off. Frequent jar tests should be made when the character and amount of the odor in the raw water changes. Threshold tests should also be made on the plant effluent and on samples from key points in the mixing basins and reservoirs in order to adjust the feed as required. Jar tests should also be run to compare different brands of carbon so that the most economical value may be determined.

When carbon dosage must be determined in a plant that lacks facilities for extensive tests, a rough method consists in the following steps:

1. Prepare a stock suspension by mixing a level teaspoonful of activated carbon in a gallon jug of substantially odor free water.

2. Add 10 teaspoonfuls of stock carbon suspension to a gallon sample of water. Mix well, then stand half an hour.

3. Filter the treated water sample through a funnel plugged loosely with a pad of absorbent cotton. Reject the first runnings; then collect about a drinking glass full of filtered water.

4. Determine by taste or odor of the filtrate if sufficient carbon was added to the sample. Repeat the test if required.

5. Calculate the carbon dosage in pounds per million gallons by multiplying the number of teaspoonfuls of stock suspension found necessary by  $2\frac{1}{2}$ .

Activated carbon doses frequently fall within the limits of 5 to 50 pounds per million gallons. A representative reduction

in threshold odor number per p.p.m. of carbon lies in the range of  $\frac{1}{2}$  to 4. However, these figures are only broadly suggestive.

**Granular Carbon.** Granular carbon is used as a 3-ft. bed of 16 to 20 mesh particles in vessels resembling pressure filters or in conventional rapid filter boxes. All exposed metal must be coated to prevent corrosion. Odor in water passing through such a bed is trapped out. Obviously there is no question of dosage as a full depth of carbon is always available for any intensity of odor. This arrangement is ideal where the odor characteristics fluctuate continuously. A few cities use their unit to catch odors left behind other treatment. The applied water must be clear, otherwise the carbon granules become coated and lose their effectiveness. There is no loss of carbon as when a carbon seeded sand filter is backwashed. A granular carbon bed may be expected to function satisfactorily for about two and a half years, after which period the carbon may be reactivated. Because of its high cost, the application of activated carbon filters to municipal practice is restricted. Chlorine residuals disappear during passage through a bed of activated carbon.

**Chlorine.** Low doses of chlorine combine with organic compounds, including phenols from trade wastes, and aggravate tastes considerably. Sufficiently high amounts of chlorine destroy most odor producing substances by oxidation, an action equivalent to burning up these compounds. Since oxidation is favored by a low pH, chlorine for odor elimination should be applied to the raw water; especially so if lime softening or corrosion control by alkali is provided. As oxidation proceeds, the orthotolidin residual generally decreases until this reaction is complete, but further addition of chlorine builds up the residual in most cases as expected. This characteristic application of chlorine has received the name "break-point chlorination." A more detailed description of its technique is given in Chapter 9.

Break-point chlorination is one of the most effective known



methods of eliminating odors from water supplies. Beyond the break-point dosage, the odor which results is usually that of excess chlorine and this may be reduced as completely as desired by such means as: allowing several hours or more contact time; addition of some form of ammonia; or by dechlorination with sulfur dioxide, sodium bisulfite or activated carbon. Once past the break-point, excess chlorine tastes lose much of their disagreeable qualities. Occasionally when an odor is not removed by this treatment, its nature is changed to one that is more agreeable.

**Chloramines.** Ammonia, in some form, is added to water before chlorination to form a series of compounds known as chloramines. As these compounds have high sterilizing power, though somewhat slower in bacteria-destroying action than chlorine, they are useful as a disinfectant. Their action is to fix the chlorine in chemical combination below the break-point and prevent the formation of chloro-tastes with phenols and similar organic impurities. The chlorine-ammonia treatment, in this way, is a preventive against many tastes which form on simple chlorination. Further details of this treatment are given in Chapter 9.

**Chlorine Dioxide.** Phenolic tastes in severely contaminated water has been economically removed by chlorine dioxide, 0.5 p.p.m. residual, formed by passing sodium chlorite solution through the discharge line from a chlorinator.

**Clay.** Clay consists of minutely subdivided soil grains. By virtue of its structure any clay may be used to absorb odors. The addition of clay to water causes an earthy odor but this secondary odor is fainter and more easily removable than one of algae origin. By previously treating the clay to satisfy its chlorine demand, the transfer of earthy odor is eliminated. Clay is widely used for the removal of colors from water.

**Ozone.** Ozone is an active form of oxygen produced in the neighborhood of high tension electrical discharges. By applying gaseous ozone to water, many odors are completely destroyed

by oxidation. Ozone leaves its own peculiar odor when injected into water but this is easily removed by aeration.

**Potassium Permanganate.** Potassium permanganate has been used in a few instances to reduce the chlorine demand and thus allow reduction in chlorine dosage and chloro-tastes. It also destroys phenols from trade wastes and removes some medicinal odors.

**Tests.** In conducting odor-reduction treatment, laboratory study should be directed along three paths.

1. Small scale trials of all available methods to deal with each odor problem
2. If activated carbon is used, to select competitive brands for greatest economy in performance, and to check on quality and uniformity of deliveries
3. Routine plant observation and control of dosage.

In the first two activities, the jar test is relied upon for the main part but is supplemented when desirable by plant scale tests. The threshold odor test is the fundamental determination in evaluating an odor. An adequate supply of odor-free water should always be on hand. Further particulars concerning these details are covered in Chapter 19.

## SECTION 4. DISTRIBUTION SYSTEM

### CHAPTER 14

## PUMPING

THE distribution pumps usually take suction from a ground storage reservoir in the case of untreated well supplies or from a clear water storage reservoir in plants employing filtration. Occasionally a deep well pump also performs high lift pumping at the same time. In most distribution systems elevated storage tanks float on the line to furnish a reserve of water under pressure, and to enable high lift pumping to be scheduled during daylight operation or in off-peak hours for low electric power rate. Operation of pumps is frequently automatic through float control switches and relays. The level in the ground storage reservoir is made to switch the deep well pump on and off while the change in pressure caused by the level in the elevated tank starts and stops the high service pumps.

**Types of Pumps.** A discussion of pumps for deep well service is given in Chapter 3. In this section, high lift pumps for supplying water to the distribution system are considered. Centrifugal pumps are now most widely used but in the older stations reciprocating pumps are still in operation. Rotary pumps are occasionally used.

**Centrifugal Pumps.** Centrifugal pumps move water by building up a pressure within the casing through centrifugal action imparted by a set of rapidly rotating blades, termed the impeller or runner. In the turbine type, water passes from the impeller through a fixed ring of diffusion vanes to build up pressure in the casing. This arrangement is well adapted for

high discharge heads. In the volute type, the impeller discharges into a spiral casing proportioned to keep the velocity of the water uniform. This type with horizontally split casing is usually selected for public water supplies. A variation of this type combines both the diffuser vane and volute casing principles.

The water entering the pump at the suction nozzle is admitted to the impellers through a hollow central eye. Impellers are single-suction or double-suction according to whether the eye opening in the suction chamber is on one or both sides of the runner. In both forms, the water passage through the impeller is closed on each side by shrouds which guide the discharge and also act as stiffeners. The double-suction impeller theoretically has the forces caused by changing the direction of flow equally balanced; however, a thrust bearing of some sort is required on the shaft. For handling abrasive liquids and sewage, the open impeller having vanes radiating out on a hub plate is commonly used.

Centrifugal pumps may be primed by installing them below the water level at the suction, by vacuum pumps or air ejectors, or by filling them with water from the tower tank or distribution system. When a foot valve is installed at the end of a suction line to hold the prime, the leather flap should bend freely, otherwise the suction head becomes excessive. Usually a foot valve may be replaced with a bell mouth suction entrance and the pump primed by means of a small electrically driven vacuum pump or an ejector that serves for all the pumps in the station. A check is placed on the discharge line between the pump and gate valve, so high pressure water cannot run back through the pump when the motor is stopped. Automatic primers are sometimes used.

Advantages of the centrifugal pump are low first cost, small space occupied, noiseless operation, simplicity, steady flow, absence of valves and air chambers, easy maintenance, and its ability to run against closed valves without harm. Disad-

vantages include the need for priming and its varying output and efficiency when the head varies.

**Appurtenances.** A gage on the casing of each pump, or connected to its discharge line, shows the pressure within the unit and enables an operator to judge if it is fully primed. Due to excessive pressure pulsations at such points, a gage usually wears out the sector teeth within the arc of vibrations and the pinion. In order to obtain reliable readings and to preserve the gage, the vibrations should be damped by means of a needle valve or a snubbing device. A needle valve is liable to clog but a vibrating piston type snubber is always open. In the snubber illustrated in Figure 31, a rod R attached to piston P oscillates

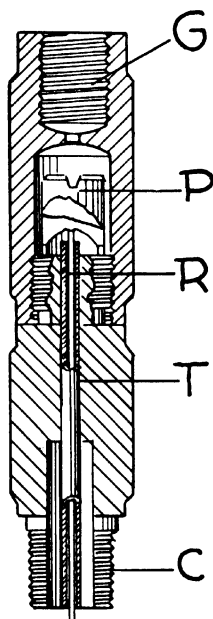


FIGURE 31

Ray Pressure Snubber

(Courtesy of Ray Pressure Snubber Company, Charlotte, N. C.)

within a closely fitting tubular passageway T to smooth out short shocks. This device is installed with the gage nipple screwed directly into the female threads G and a gage cock connected on the male threads C.

A meter should be placed on each feeder main leaving the pumping station to keep check on the consumption in each area served, and to have a quick indication to aid in locating water main breaks. A master meter is provided in large stations to sum up, hydraulically, the total flow from the pumps. Long lines fed by centrifugal pumps should be protected against surges, following shut-off, by an automatic quick check valve closure before the arrival of the high pressure wave at the station.

## MAINTENANCE OF PUMPS

### **Items in Centrifugal Pump Care**

1. Screen suction pipe intake to keep accidental trash from reaching pump.

2. Lubricate bearings properly according to manufacturer's recommendations. Sleeve bearings are oiled; insufficient oil allows wear. Ball or roller bearings are greased; excessive grease or grease of too heavy consistency causes friction, heat and power loss. The main function of grease here is to protect the polished steel surfaces against corrosion. Excessive wear at bearings reduces efficiency of the pump and endangers its closely fitting parts.

3. Preserve alignment of pump and motor. The coupling flanges should be parallel vertically, as tested by a feeler gage, and axially, as shown by a straight edge. An eccentric connection will load the bearings excessively; flexible couplings will correct only slight misalignments. Misalignment may develop later through settlement of the foundation, motion in connected piping, or loose bolts.

4. Pitch horizontal suction pipe slightly upward toward the pump in order to avoid air pockets which might cause a loss of

suction. The suction line reducer should be the eccentric type, with horizontal part upward. A cock for drawing air from the pump should be screwed in the top of the casing, particularly for pumps idle for long periods.

5. Do not allow the piping to place a strain on the pump casing. Piping should be self-supporting and connections should meet without force. By springing the pump casing, closely fitted parts may grind together.

6. Never run the pump dry. Water acts as a lubricant between rings in the water lubricated type of bearing. Remove any air that accumulates during pumping by opening a pet cock at the top of the casing. See that packing does not allow air to leak into the suction chamber.

7. Examine wearing rings regularly; replace if worn to greater than 0.030 to 0.050 inch clearance or if exceeding manufacturer's tolerance.

8. Replace packing periodically as manufacturer's instructions recommend. Do not force in an extra ring of new packing as this may displace the lantern ring which admits high pressure lubricating and sealing water to the packing. Excessive pressure on the packing will score the shaft. If the supply is not chlorinated, sterile packing should be used particularly inside the lantern ring, otherwise the water may be contaminated. Examine the old packings, noting type of wear as this gives a clue to the condition of the pump. To insert packing, first clear the stuffing box thoroughly, then place each ring in position separately, and seat it firmly by following with the gland and tightening the bolts by hand. Remove the gland and add the next ring. Stagger the joints in adjacent rings by 90°; spot the joints in a clockwise direction for easy relocation when removing. With final ring in place, the gland is placed in position by tightening the bolts with fingers only. Adjust the pressure so that a thin trickle of water leaks through the stuffing box to lubricate the packing.

9. If the shaft or sleeve next to the packing is roughened

or grooved, it should be turned or ground to a smooth surface, so that packing will remain fitted. When badly scored, these rotating surfaces may be rebuilt to original dimensions by hard surfacing, metallic spraying or electroplating; then machining or grinding to dimensions. When repair is impractical, a badly scored shaft sleeve should be replaced.

10. Generally, the total suction lift, including friction loss, should be limited to 15 feet or less.

11. Suction piping should be at least a size larger than the suction nozzle. The water velocity should be below four feet per second. Minimize friction by using as few and as flat bends as possible, and selecting smooth pipe. Valves should be wide open. Joints should be air-tight. A test with a candle flame will reveal leaky joints. Where a strainer is used at the foot valve, the net clear area should be three or four times the cross section of the suction pipe. The suction inlet should be sufficiently submerged to avoid sucking air in eddies.

12. Operate the pump near its rated head. Operations at other heads will reduce its efficiency and useful life. Cavitation, or air release at the impeller, is increased at higher speeds and wears away the blades. Sharp cracking noises indicate impact.

13. Keep the motor drive in condition. Connection should be across the line to receive full voltage. Direction of rotation should agree with the directional arrow on the pump casing.

14. When a pump casing is opened for repairs, the water passage should be sprayed, brushed, or filled with strongly chlorinated water (2–10 p.p.m. orthotolidin residual) for a few hours before placing in operation. Too heavy chlorine doses and excessive exposures should be avoided; if rusting starts, the chlorinated water should be flushed away immediately to prevent roughening steel surfaces and reducing the efficiency of the pumps.

15. Idle pumps should be run under power weekly.

16. If the starting load on the motor is too heavy, the pump



should be started with the discharge valve (not the suction valve) nearly closed. After reaching speed, the discharge valve is opened wide. Running with this valve partially closed wastes power.

**Efficiency.** The efficiency of a pump or of any other machine measures that fraction of the energy supplied to the prime mover, generally a motor, eventually recovered as effective work. Electrical energy is measured as kilowatt hours (kw. hr.) and may be read from the switchboard meter or from test instruments temporarily placed in the motor circuit. For this purpose, a voltmeter and external-grip ammeter are the most convenient. The energy imparted to the water is determined from the rate of pumping and the difference between the suction and discharge heads. The combined efficiency of a motor-pump set may be calculated from the following formula:

% Efficiency

$$= \frac{\text{g.p.m.} \times \text{total head (ft.)} \times \text{hours pumped} \times 0.746 \times 100}{3960 \times \text{kw. hr.}}$$

$$= \frac{\text{g.p.m.} \times \text{total head (ft.)} \times \text{hours pumped}}{53.1 \times \text{kw. hr.}}$$

The total head comprises the suction lift, in feet, plus the discharge head, in feet. When the suction is under pressure, its value in feet is subtracted from the discharge head in order to obtain the total head. Altitude gages should be installed at the same elevation as the center line of the pump or suitable corrections made to their readings. A small correction for the "difference in velocity head" is made in exact tests if the suction and discharge gages are not tapped into pipes of the same diameter.

*Example.* A 300 g.p.m. centrifugal pump lifts water from ground storage reservoir level, 7 feet below the pump shaft, and discharges against 120 feet head. What is the total pumping head? If the pump operates for 20 minutes and consumes 3.5 kw. hr. on the meter, what is its "wire to water" efficiency?

Calculation. Total pumping head =  $7 + 120 = 127$  ft.

$$\begin{aligned}\% \text{ Efficiency} &= \frac{300 \times 127 \times 1/3}{53.1 \times 3.5} \\ &= 68.4\%\end{aligned}$$

A simple method for checking overall efficiency from data on the monthly report sheet consists in applying the formula:

$$\% \text{ Efficiency} = \frac{\text{Total Head} \times \text{gal. per kw. hr.}}{318,200}$$

Efficiencies range in practice from below 50 to over 80%; larger sizes generally show the higher efficiencies.

**Pumping Characteristics.** A so-called "characteristic curve" for a typical centrifugal pump operated at constant speed is shown in Figure 32. The highest discharge pressure that can

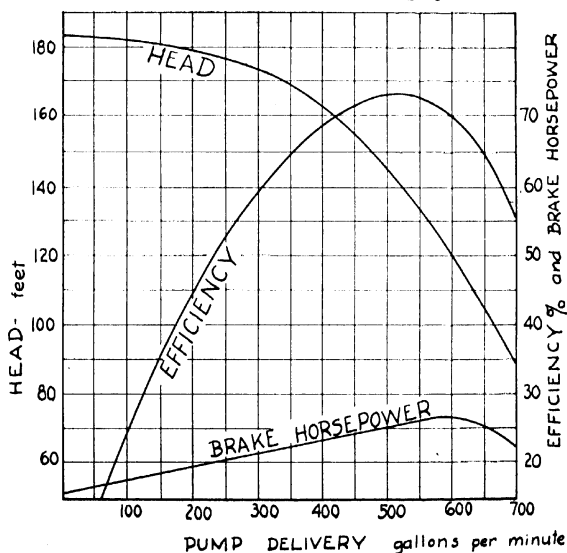


FIGURE 32

Characteristic Curves of a Centrifugal Pump at Constant Speed

be developed is obtained by rotating the impeller with the discharge valve closed. The water is then churned around the casing, producing a so-called shut off head. As the discharge valve is gradually opened, this pressure falls off with the amount of water pumped. The horsepower consumed also decreases with discharge because of the decreasing pressure. Increasing with the rate of pumping, the efficiency reaches a maximum at full load and then falls off somewhat sharply.

In selecting a pump, one should be chosen to reach full load efficiency under the prevailing pumping conditions of head and discharge. A first-class pump in both design and workmanship is usually more economical than a cheaper pump of lower efficiency. Pumps should always be tested as a part of their installation to determine if the expected capacity and efficiency is reached. During later routine operation, these tests should be repeated occasionally, or some equivalent observations taken to watch for signs of depreciation.

When the speed of a pump changes, so do the characteristic curves. Highest efficiency is obtained only at the rated speed, therefore this should be the speed of operation. The effect of changes in speed on the action of a pump can be approximately figured (without about 5%) from the relations:

quantity pumped varies as r.p.m.

head developed varies as (r.p.m.)<sup>2</sup>

horsepower required varies as (r.p.m.)<sup>3</sup>

If a pump is oversized and a smaller discharge is desired, the discharge valve should not be throttled, or operated partially closed, as this act wastes power. When possible, the extra capacity of the pump may be utilized by providing sufficient storage and running the pump intermittently; this prolongs the life of the unit. If the motor is a type that can be slowed, this change will reduce the pump capacity but with a decrease in efficiency. Smaller discharge, when using a constant speed pump, is best obtained by turning down the diameter of the impeller blades on a lathe. The relation used is that the quantity

(g.p.m.) varies as the diameter. Before making such a change, the manufacturer should be consulted for specific recommendations. Similarly, when the pump output is low and fails to develop the full power of the motor, a larger impeller may usually be purchased, at a nominal cost, from the manufacturer. The demand for variable output in large stations is met by having the pumping units of different size.

**Other Types of Pumps.** Reciprocating pumps, installed before the era of motor-driven centrifugal pumps, still operate in a few older stations. Pumping is accomplished by direct piston displacement; the double acting type, with discharge and suction occurring at the same time on opposite sides of the piston, is the usual arrangement. Spring retained valves regulate the entrance and exhaust of water from the cylinders. Cylinders are usually in pairs, having a flywheel mounted in between to smooth out the rotation. A vacuum and air chamber on suction and discharge aid further to level out fluctuations in flow during a stroke. These pumps, being slow speed machines, are durable, reliable and show high efficiency. Since they pump by positive displacement, the discharge valve cannot be shut while the pump is working, as with a centrifugal pump.

Rotary pumps operate by positive displacement; water, in an enclosure between two intermeshing rotors or between a rotor and one or more stator parts, is forced out at each revolution. The double rotor variety is widely used for thick fluids. Efficiencies decrease during service as a result of the contact and wear of closely fitting parts. A screw type rotor is being used for pumping water.

**Sources of Power.** A great majority of pumps are powered by electric motors; only a few steam engine drives are still used. In locations where fuel is available cheaply, a gas engine may furnish power with considerable economy. Where dual power is required for operation during electrical breakdowns, a gasoline engine, gas engine, or Diesel engine is provided. These secondary sources of power may be connected

to an extra pump, or to the usual service pump shaft by means of a loose coupling. Generally, the prime movers are directly connected to the pump; occasionally gear or belt-drives are used.

**Motors.** Motors should be liberal in size; for pumps taking under 100 h.p., the motor should have a horsepower rating at least 120% of the pump demands. Where direct current is used, a shunt wound, constant-speed motor is suitable for usual operation; but for high starting torques, as in automatic-controlled stations, the compound wound type is chosen. Direct current, variable-speed motors draw the same current at low as at high speed, with certain exceptions, therefore, are uneconomical except at full speed. Alternating current is much more frequently used and the following types of motors, given in the tabulation, are suited for pumping.

TABLE 10

## Types of Motors Used for Pumping Water

| <i>Type of Motor</i>  | <i>Advantages</i>   | <i>Disadvantages</i>   |
|---|---|--|
| Squirrel Cap Induction  | Least cost, rugged, simple, no moving brush or wire connections, suitable for manual or remote control, high efficiency | Low starting torque, low power factor, requires large transformers and lines, constant speed fixed by number of poles and frequency, highest cost for power used |
| Widely used for constant-speed pumping, particularly for small pumps. |   |  |
| Slip Ring Induction or Wound Rotor                                    | High-starting torque, variable speed  | Cost 15 to 20% higher than for squirrel-cage type, low power factor, requires large transformers and lines   |
| Used for variable-speed pumping, where head varies.                   |   |  |
| Synchronous   | Permits power factor correction, and favorable power rates, high efficiency, reliability                                | Constant speed, external excitation of fields needed, usually by a small generator on end of shaft, low starting torque, costs more than induction motor         |
| Use for constant-speed pumping, competitive with slip ring motor.     |   |  |

By pumping during off-peak hours, stations purchasing power are able to secure reduced rates.

## MAINTENANCE OF MOTORS

1. Keep dust removed. Dust insulates windings against the loss of heat thus interfering with proper cooling; a mat of dust will retain oil and moisture. On slip rings and commutators, dust causes wear and poor electrical contact. Wipe off housing and rings regularly, and blow the dust from the windings with a clean air jet (never above 40 psi. pressure) or hand bellows. Keep oil cups closed to prevent access of dust to bearings.

2. Keep free from stray lubricating oil. When oil-soaked, the insulation is softened and liable to burn out. Good contact is impossible with dirty commutators or rings. Oil and dust deposits are removed by carefully scraping, or wiping with a solvent like carbon tetrachloride. Avoid soaking the insulation. Never lubricate oil ring reservoirs while the motor is running, as overfilling and spread of oil may follow when the motor is stopped.

3. Keep motor as dry as possible. If a megger test shows a low insulation resistance due to moist conditions, the motor may be dried by passing a low voltage current through the windings with the armature locked stationary. A fan to blow air through the windings aids evaporation. During long idleness, cover the motor with a tarpaulin and keep dry by the heat from a couple of light bulbs. When flooded, a motor may be reconditioned by controlled oven baking, by infra-red rays, or by a bath in hot paraffin.

4. Keep bearings properly lubricated according to manufacturer's recommendations. Bearings should be inspected at least weekly. Oil rings in sleeve bearings should rotate freely with the shaft.

5. Keep motor and pump in correct alignment. Burned-out bearings, bent shafts and damage to the pump may result from misalignment, caused by faulty installation or later-effects such

as settlement of foundations, excessive belt tension, or wear at the bearings. Vibration or noise may indicate this condition. Change position of motor or adjust shims under motor legs until units are aligned. Keep mounting bolts tight. Replace bearings if feeler gage shows an uneven air gap around the circumference of the rotor.

6. Eliminate vibration. Vibration may be caused by misalignment, loose mounting bolts, play in bearings in excess of 0.002 inch plus 0.001 inch per inch of shaft diameter, or lack of dynamic balance in rotating parts of motor or pump.

7. Keep commutator or slip rings smooth. Good operating condition is indicated by a clean, polished brown color; a bluish color signifies overheating. If worn in grooves, resurface by means of a commutator stone; never use emery cloth nor an emery stone. Reset brushes or renew them if more than half worn. Check brush pressure and clean brush holders if dirty.

8. Do not overload the motor. The resulting heat may melt soldered connections and bake the insulation. Overload protection is obtained by an overload relay or proper sized fuses.

9. Avoid underloads on induction motors.

10. Examine starter, switch, fuses and other controls weekly. The motor should never become so hot that an operator cannot keep his hand on the housing. Contact points on the starter switch should be kept in good condition; otherwise a lowered voltage at the motor terminals may result. A record should be kept of findings at each periodic inspection. Most manufacturers furnish on request a card file to enable an operator to check a motor to best advantage. Repairs should be attempted only by a properly qualified electrician.

## CHAPTER 15

### RESERVOIRS

**Ground Storage Reservoir.** Ground storage reservoirs perform the following useful functions:

1. Provide a reserve supply of water in case of shut down at a well or a high demand during fires.
2. Act as a sand trap to settle out grit from the wells.
3. Furnish a central tank into which all wells from a given area may discharge to supply the high lift pump.

Where water of different chemical characteristics is mixed, sufficient dilution may be had to reduce an objectionable quality to within acceptable limits.

4. Enable wells, deficient in yield or pump capacity, to suffice by allowing storage of slack hour production.

5. Allow use of purchased power for pumping during off-peak hours, with a substantial benefit in electrical rates.

6. Permit automatic operation of well pump by float-controlled switches.

7. In cases of break-point chlorination, provide contact time for dissipation of excessive residuals.

The usual construction is of reinforced concrete, circular or rectangular in plan, with the top slightly above the ground level, close-by the pumping station. Occasionally, a steel tank with its bottom resting on a mat at ground level is used. Water tightness is essential to prevent loss of water when the reservoir is full and to keep out contamination by surface drainage and shallow ground water when the inside level is low. The concrete should be properly reinforced and the expansion joints made water-tight. By means of the Hewett System of pre-stressing the reinforcing, concrete tanks may be built to resist



forces that cause cracking. During setting, the concrete should be waterproofed by keeping flooded or covered with wetted sacks for two weeks after pouring. Otherwise, the concrete should be cured by applying a water glass solution, one volume of water to two volumes of sodium silicate, or a lacquer type compound to the green concrete after the initial set. The adjacent ground surface about the reservoir should be graded to drain rainfall away from the structure. Shallow ground water may be kept out of the nearby area by placing sub-surface drainage to lower the water table to below the bottom slab.

A watertight roof, of concrete, galvanized iron or roofing felt, is always provided to keep out contamination by rainfall, dust, and insects. As an additional advantage, a roof keeps the water cool and shaded in summer; lack of sunshine prevents growth of most algae. A vent is provided on the roof to allow filling and emptying without creating pressure or vacuum. Its opening is screened against insects. The water level is indicated usually by means of a simple float gage extending through a leakproof thimble; its index moves across a scale mounted on the roof of the reservoir.

Overfilling is prevented by an overflow outlet, usually a six-inch pipe, entering through the wall near the top and discharging through a screen by free fall to some sort of apron provided to prevent the soil from washing away. A manhole on the roof allows access for inspection. The manhole ring should stand a few inches above the roof surface to prevent entrance of water during rains and the lid should lip over the top of this ring to stop seepage around the edge of the cover. To guard against tampering, the cover should always be locked shut by means of a hasp and stout padlock. A drain hole is usually provided for washing out the reservoir; its discharge, whenever possible, should be to the open, never to a sewer.

**Maintenance.** Ground storage reservoirs should be inspected periodically for cracks. A leaky bottom or wall may be

demonstrated by filling the reservoir and noting the drop of the water surface after standing undisturbed overnight. Small cracks may be caulked by drying the concrete nearby and applying hot tar. Larger cracks should first be tightly jammed with some packing material like jute. These cracks may also be patched with concrete if they are first chipped to an open V form. Certain proprietary sealing preparations, applied according to directions, will stop even the most persistent leaks. Grouting by means of a hand pump also seals up channels leading to cracks in the concrete floor and lower walls. Sometimes, an impervious terrace of clay banked around the upper portions of a reservoir will accomplish a tight seal.

Slimy growths on the walls may be removed by spraying or brushing on a solution of copper sulfate. Directions for applying a copper sulfate whitewash are given in Chapters 7 and 8. Copper silicate is now being introduced for use to replace the soluble, therefore, impermanent, copper sulfate application. Sand and other debris should be removed from the reservoir periodically. After a reservoir has been inspected or repaired, always precede restoring the reservoir in service by disinfection with a strong chlorine solution, usually a 0.1% solution of HTII sprayed or painted over the walls. An alternate method of disinfection consists in chlorination of the water to give a residual chlorine test of 2 p.p.m., filling the reservoir as high as the overflow pipe, allowing this strongly chlorinated water to soak overnight, and then discharging to waste. When the water first filling the reservoir is desired for pumping to consumers, the residual is kept below 0.5 p.p.m. of chlorine in order to reduce complaints due to taste. Details for calculating the weight of chlorinated compounds needed are given in Chapter 18.

**Elevated Storage Tank.** Elevated tanks, floating on the line in the distribution system, provide the usual benefits accompanying storage such as a reserve supply under pressure,

smoothed out pumping peaks, smaller size pumping units and ability to schedule pumping during hours of low electrical demand. In addition, elevated storage also:

1. Provides for automatic start and stop of service pumps by float controls or pressure switches.
2. Preserves pump pressure when pumps are idle, if located close to a pumping station.
3. Provides additional volume for a fire pump to draw suction, if located nearby.

For this purpose, the tower is cut off during a fire and its contents dropped through a line above the shut off valve into the ground storage reservoir from which the fire pumps feed.

4. Reinforces feeder main and minimizes loss of pressure, particularly during hours of heavy draw off, when located in or on the far side of the sections having the heaviest consumption.
5. Allows opportunity for chlorine contact time and special iron removal treatment in small systems which are relatively idle during the night.
6. Provides surge space to cushion water hammer when stopping centrifugal pumps.

Elevated tanks are usually made of steel plates and are set on steel framework towers. A few tanks and towers are made of reinforced concrete. The design of the tank and tower should harmonize with the surroundings, whenever attractiveness is preferable to standardized shapes. Ellipsoidal roofs and special bottom plate sections, having all-welded seams, provide structural strength to hold large volumes, with relatively slight variation in available head between high and low levels. When an elevated location is available close to the pumping station or to the high demand district, the tower is reduced in height correspondingly or may be omitted entirely. In this case, the same maintenance problems arise as in a ground storage reservoir. The minimum tank size is fixed by fire protection regulations at 50,000 gallons, set on a platform to give 100 feet head. Stand-pipes are no longer built for elevated storage, because

the water at levels below the top section is not available, except at low pressure. Water is pumped and discharged through a riser pipe, which is frostproofed by using a pipe of large diameter or by insulating with a cover tube. This riser protrudes a foot or so above the bottom of the tanks in order to provide a space for the accumulation of sludge and thus avoid returning this material to the distribution system. A separate small draw-off pipe drains this section. The balcony floor should be perforated at places to permit water to run off. A watertight roof through which birds cannot enter, and an overflow pipe which acts as a breather, are also provided.

**Maintenance.** Tanks should be inspected regularly at six-month intervals after the first two years of service. Maintenance of elevated tanks is concerned mainly with protection against corrosion, both externally and internally. Corrosion of tower parts and the tank exterior is prevented by paint. The surfaces must be properly prepared beforehand by means of sand blast, chipping hammers, or scraping with a wire brush; then covered with two coats of primer followed by a finishing coat of aluminum, aluminum-graphite, or asphalt base paint. Lead chromate primer is superior to red lead and oil. No larger area should be sand blasted than can be painted the same day. Avoid painting on damp days. Painting should not be applied over mill scale, as this flakes off when water, creeping underneath, causes rusting. Steel surfaces can also be effectively cleaned by means of flame priming with a wide head oxy-acetylene blow pipe. Molten zinc, sprayed about 0.006 inches thick on clean roughened steel surfaces, gives long term protection. Reinforced gunite, a concrete made with pebble aggregate, and shot forcibly into position by an air gun, is an effective protection on the inside and outside of steel storage tanks resting on elevated ground; such tanks are permanently attractive without further painting.

Leaky plates and rivets can usually be repaired by hand caulkink tools. Pits, completely eaten through the plate, are best

plugged by inserting a patch bolt. Otherwise, pits are painted to stop further penetration. Welding may cause other leaks to appear and should not be attempted. Spider rods, across the top of the tank underneath the roof, have no permanent value after erection is completed, and need not be replaced if rusted out. Adjustment of sway rods, made during original building, is rarely necessary and, if needed, should be done only by an expert so that the stresses are distributed uniformly throughout the tower. Diagonal wind rods should not be removed for cleaning or repairing, except when the tank is empty, the weather calm, and only if false struts and guy wires have been placed to prevent a possible collapse. Rust is likely to be found under the clevis pins and rod loops. Base plate enclosures, likely to trap dirt and water, should be cleaned, painted, concreted to their tops and graded to shed water; or a 1½-inch hole drilled through the channel section for drainage. Ladders should be kept well protected for safety.

Internal corrosion is prevented by cleaning and painting, as described for the exterior of the tank. Toxic materials cannot be used. Coal tar paints or any others that form tastes with chlorinated waters should be avoided where the supply is chlorinated. Natural and petroleum asphalt base paints are widely used for the finishing coat. As their solvents are volatile, unhealthy, and explosive, a positive circulation of air should be provided by a portable blower. During the hot months, painting can be done at night to avoid the discomfort of high temperature.

Positive corrosion protection is also furnished by cathodic protection, as described more fully in Chapter 12. For this purpose, insulated anode rods are raised to a slight positive voltage by a small rectifying unit; the tank shell is grounded. For waters above pH 7.0 a 30% chromium anode lasts indefinitely; graphite anodes disintegrate under these conditions. A grey-white alkaline film forms on the plates, and underneath the steel is excellently preserved. If in poor condition, the paint

film will be pushed off by the deposit; otherwise, pin-point holes will become plated. By alternately reversing the polarity, the surface is cleaned better than by sand blasting. An accumulated alkaline deposit may last several months without current; therefore, the voltage should be adjusted just to hold a sufficient thickness of film.

At the water line, corrosion is particularly severe. Above a three-foot submergence and covering the inside top of the tank, a bakelite base paint or hot pitch should be applied.

Following the inspection or repairs, the inside of a tank should be chlorinated before restoring to service. Pouring a strong solution of HTH or bleaching powder, sufficient to give a residual ranging from 0.5 to 2.0 p.p.m. chlorine after dilution, through a hatch into a small amount of water admitted to cover the floor, then filling the tank is one method sometimes used but opportunity for mixing is too uncertain for best results. Spraying an HTH solution having 10 to 25 p.p.m. residual chlorine directly on the steel surfaces is effective. Elevated tanks are most conveniently chlorinated by injecting a clear chlorine solution in the suction of the high lift pump.

## CHAPTER 16

### PIPING AND CONNECTIONS

**Distribution Piping.** Piping in the distribution system proper includes feeders, the network of mains, valves and service connections. The feeders and distribution network should be adequate to supply the normal needs of the consumers plus fire protection. Class B pipe, built to withstand heads from 100 to 200 feet, is usually specified. Arrangement and size of piping depends on the number of consumers, whether domestic, commercial or industrial, area, pressure maintained, topography, storage provided, expected population growth, direction of real estate developments and fire requirements. Mains should be looped when possible to provide a dual direction of feed and to avoid dead ends. Detailed maps of the system should be on hand for quick reference when needed.

A water line should not be laid in the same trench with a sewer line; if closer than 10 feet, the water line should be at the higher level. Wherever these pipes cross, the sewer line should be cast iron with lead joints for a distance of 10 feet from the water main. Under-water crossings at streams likewise should be avoided and the main carried on a bridge or trestle whenever possible. Otherwise the main, jointed with flexible, watertight connections, should be buried to a depth of five feet beneath the bed of the stream in order to avoid damage by traffic or debris. Ground cover for protection against frost and vibrations from traffic in streets should be from 2 to 2½ feet. At crossings underneath a railroad track, where extreme conditions of weight and vibration are met, the main should extend through a thimble of larger pipe, or have a rubber ring compression type of joint.

In extending lines, the general plan of a completed lay-out should be followed; thus, a six- or eight-inch line may serve a given area until its development justifies a larger feeder on a street reserved for its installation. On wide paved boulevards, the two-main system is sometimes favored for its economy in making or repairing consumer service installations. Each side is supplied from the nearer main, one smaller than the other for service in a single block section only, while the larger main runs the length of the street.

Valves should be sufficiently numerous to shut off small sections when required; thus in the high-value district valves should be located to isolate every 500 feet, in the residential district 800 feet. Two gate valves are commonly placed where mains intersect. Air relief valves are placed at the high points of the system, and blow-off valves at the low points for the removal of sediment. Settlement is prevented by setting the valves on a concrete base. Valve locations should be standardized, as on the extension of the property line with a main. All valves in a system should turn in the same direction.

All valves should be inspected and operated at least yearly. A small amount of penetrating oil is poured down the stem to lubricate the packing gland and soften up the packing. Stems that develop leaks on turning should be repacked. Rust and sediment in the valve is removed by shutting the disc hard in the seat, then opening about a quarter-way and closing tightly several times; the increased velocity usually flushes obstructions away. Valve boxes should be reset to grade when covered over by dirt or paving. A record card should be kept on each valve showing size, direction for turning, number of turns, inspections, repairs, and whether open or closed. Occasionally, valves are accidentally left partly or wholly shut, causing undue loss in pressure at points below. This condition can be revealed by special surveys that relate flow and pressure loss. A spot map showing the location of principal feeders and valves can be drawn on a plywood board, using curtain grommets to repre-



sent valves. Open and closed positions can then be indicated by twisting the grommet a quarter turn. This map should be covered by a locked glass panel to prevent unauthorized meddling.

## PIPE MATERIALS

**Cast Iron Pipe.** Water mains generally are of cast iron; this material has durability, strength, good corrosion resistance, except to aggressive waters and corrosive soils, and is readily available. Ordinarily these pipes are hot dipped in coal tar pitch to protect them against corrosion. Cement lining is used to prevent corrosion by active waters. By coating this lining with a tarry or so-called bitumastic enamel a smooth mirror-like interior of superior carrying capacity is obtained which resists corrosion and leaching. A cement lining may be applied to old mains in place by pulling a centering mandrel through a dry 1:2 mortar introduced into the pipe, according to the Tate method. In pipes of thirty-inch diameter and larger, the Centrifugal process is used to apply cement by means of a centrifugal spreading machine, followed by a mechanical trowel. Cement linings 1/16 to 3/16 inches thick hold tightly and do not chip off when tapping through the side wall for pipe connections. Exterior cement casing and bituminous paints with kraft paper wrapping protect metallic pipes in corrosive soils.

*Joints.* Joints in cast iron pipe are made by filling to within two inches of the face of the bell with yarn, either jute, hemp, rubber, or paper substitute, then pouring lead to fill the joint. Since lead shrinks on cooling, it must be expanded into a tight fit by caulking. Too heavy blows may split the bell. Lead wool is sometimes used in wet trenches. Lead joints have the important advantage of permitting caulking under pressure when leaks are found.

Lead substitutes, available at a smaller cost, offer the advantage of "taking up" shortly after pouring to form a tight

joint. Should leaks develop, these also seal up in many cases. No caulking is required as the material, a mixture of sulfur and iron filings, expands slightly after solidifying in the joint. When leaks are caused later by deflection of the line, the slow trickle of water is slightly acidified by the sulfur and corrodes the iron filings into iron oxide which, being of greater bulk than the original metal, swells the joint tight again. Sulfur compounds must be poured at the proper temperature, obtained by melting the mixture over a wood fire; otherwise, the molten mass, if too hot or too cold, will be too thick, and the joint will be defective. Since a sulfur joint is unyielding, the connection of a new line, likely to settle, to an old line should be made with a lead joint.

Cement joints have been used for pressures as high as 150 psi. After yarning, the joint is stuffed half full of barely wetted mortar, this is rammed forcibly with a caulking iron. A second round of mortar is then placed and calked the same way. Water pressure may be applied in 24 hours; sweating joints soon seal.

Flexible joints are used for lines laid on stream beds so that pipe may be laid from barges. Bronze welded joints withstand extreme conditions, but an expansion joint or a flexible joint is needed every 6 to 8 lengths. Flanged joints give tightness, strength, and rigidity. Tapered joints with machined fit are used on Universal pipe; these are easily assembled merely by tightening two bolts. Dresser and Skinner couplings are rubber ring compression joints and are applicable where speed, flexibility, and water tightness must be assured. Solid sleeves are used to make repairs over short cracks. Stub ends in pipes over eight inches in diameter should be harnessed by bolts or buttressed to prevent the joint from blowing out.

**Asbestos-Cement Pipe.** Pipe made of Portland cement and asbestos fiber rolled to a dense structure over a mandrel, or formed by the extrusion process is unaffected by soil corrosion or corrosive waters. The joint in "Transite" pipe con-

sists of a sleeve which holds rubber rings in a groove; these connections are quickly made and may be flexed through a 12° angle without leaking. "Century" pipe is joined by means of a Dresser coupling. Asbestos-cement pipe costs slightly less than cast iron; its flow capacity remains unimpaired, but its strength is only about one quarter that of cast iron pipe. The pull-out strength of a service connection may be improved by tapping the main horizontally, rather than at the usual high 45° insertion; also, a liberal length of gooseneck should be allowed. Taps should not be transferred between usage with iron and asbestos-cement pipe.

**Other Pipe.** Steel and concrete pipes are sometimes used in long pressure lines but rarely as distribution mains.

**Service Pipes.** Service pipe may be lead, tubeloy (a lead alloy with small amount of magnesium, calcium and tin), copper tubing, brass, black or galvanized iron and steel, and cement-lined or lead-lined iron and steel. Lead should not be used with corrosive water. Copper is favored where long life is desired. Plastic pipe and tubing, particularly the vinylidene chloride type such as Saran, has the advantage of flexibility, frostproofness and strength at hot water temperatures. Cellulose acetate butyrate types, while tough at room temperature, become too plastic for sufficient strength with hot water. These plastics become brittle at freezing temperatures. Services requiring larger than a two-inch corporation cock are furnished through several manifolded smaller goosenecks in order to avoid weakening the main by drilling a large hole.

**Laying.** Except where soil is nearly saturated with water, the shallow trenches used for water lines do not require bracing to prevent cave-ins. Tree stumps which might concentrate the load at one point along a pipe length should be cut out below grade, and the hole refilled with tamped earth. A cradle should be dug out to receive the bell. The pipe should be handled by a derrick or rope hoist and skids to prevent breakage in the field. A final inspection by sounding for breaks or cracks

should be given each length before lowering into the trench. Placing the ends of a length on blocks is not good practice, as the pipe there acts somewhat as a beam with the load concentrated near the ends. The earth should be tamped tightly around the bottom half of the pipe, and then earth thrown in to cover the top of the pipe. This also should be well tamped for uniform bearing about the pipe. The remainder of the trench is then backfilled. Tamping of this section is of no direct benefit to the pipe but minimizes settlement and ruts in the street and later traffic vibrations. Where cheaply available sand is sometimes used to backfill, as this material is easily packed and does not suffer shrinkage while it dries out. Flooding a backfilled trench with water by shoving a hose nozzle down to the top of the main is sometimes used to consolidate the soil. This method is applicable only to sandy earth which moves readily when wet. With clayey backfill there is no substitute for continuous tamping; an air-driven tool is much superior to manual effort for this purpose.

A pressure test for leaks, at 50 psi. above normal pressure, should be made before backfilling over the joints. Air should be released at high points before building up pressure with a portable pump. Leakage is usually specified not to exceed 100 gallons per day per mile per inch diameter.

Much trenching can be eliminated across lawns and highways, for pipe sizes up to about 4 inches, by pushing lengths into place with a special jack.

**Cleanliness.** Dirt of all sorts should be kept out of the pipe while handling; the trench should be kept dry. After easing into position in the trench, the front end of each pipe length should be closed by a wooden plug until the next section is ready to be laid. A snugly fitting swab is pulled through by a long wire as laying proceeds. Workmen should be supplied with portable toilets so located as to keep excreta from the trench. Before placing in service, a pipe-line should always be chlorinated, as newly laid mains are invariably contaminated.

A procedure for disinfecting new mains is fully described in Chapter 9.

**Leaks.** Important leaks may sometimes be found by noting an increase in the volume metered at the sewage disposal plant, or by watching for storm sewer or open ditch flows during dry weather. Isolated sections are checked for leaks by shutting off all valves and supplying water through a meter into a fire hydrant; the registry is compared with the sum of the readings at the consumers' meters. Over-all monthly checks for the whole system normally should account for over 85% of the water pumped. Flow and frictional data obtained from surveys may also disclose the existence of leaks and partially opened valves. Geophone surveys for leaks are best made at night.

## PIPE FRICTION

**Selection of Size.** Loss of head due to friction of water in pipe-lines depends on the velocity of flow, the diameter of the pipe, the smoothness of the wall and the length of line. For usual distribution calculations, tables based on the Williams-Hazen formula, such as Table 11, are used. Special slide rules, based on this same formula, solve directly and without effort typical problems involving length of line, size, allowable pressure drop, smoothness or "C" value and rate of flow.

For transmission lines, as from a distant source to the treatment plant, a pipe size is selected so that the over-all cost of power absorbed in friction plus the capital charges on the line is a minimum. Obviously, a larger size causes less friction loss but imposes greater charges on invested capital; an undersized line, though lower in first cost, wastes power excessively through friction. A simple approach to the selection of an economical pipe-line for a desired delivery is to maintain velocities within a certain range of values. These velocity ranges depend on local unit costs, and are higher for the larger size piping. In Table 11, the economical velocity range likely to be met in practice is indicated by the zigzag box enclosures

in each column. If a pipe is required to furnish 1,500 g.p.m. either a fourteen- or sixteen-inch size is selected from the table; a closer comparison may then be made on the basis of local conditions.

For reinforcement in an existing distribution system by means of a new feeder, the available head loss is fixed by pumping station pressure at one end and the desired residual static pressure at the far end. A size of line is selected not to exceed this pressure drop when delivering the required flow, as usually set by fire fighting requirements. Allowance should be considered for maximum recorded demand and for future developments in consumption. This problem is frequently complicated by alternate choices that should be investigated, such as the value of elevated storage, graduated pipe sizes as needed for intermediate points, different C values in the system and new looping in the network. A simple approach to the problem of planning new mains and laterals is provided by the fire flow test (See page 229).

*Example.* A fire flow test at the outskirts, recently built up with high value residences, 4,500 ft. from the plant, delivered 250 g.p.m. corrected to 20 psi. residual static pressure (see page 241), but 500 g.p.m. are desired. The test was run at the hour of high daily demand; the pumpage on the flowmeter read 1.1 MGD before starting the test, and the normal static pressure at the test site was 43 psi. Pump pressure is carried at 60 psi. The previous peak domestic and industrial rate was 1.8 MGD. If a single new feeder is to be tied in at this area, select the proper size of pipe.

$$\begin{aligned} \text{Solution. Allowance for 25\%} \\ \text{excess in maximum demand} &= 1.25 \times 1.8 \\ &= 2.25 \text{ MGD} \end{aligned}$$

$$\begin{aligned} \text{Approximate expected maximum} \\ \text{pressure loss} &= (60 - 43) \times \left( \frac{2.25}{1.8} \right)^2 \\ &= 17 \times 1.25^2 \\ &= 26.5 \text{ psi.} \end{aligned}$$

|   |   |
|---|---|
| Expected minimum normal static pressure           | = 60 — 26.5                                     |
|   | = 33.5 psi.                                     |
| Available fire flow at 43 to 20 psi. difference   | = 250 g.p.m.                                    |
| Available fire flow at 33.5 to 20 psi. difference | = $250 \times \sqrt{\frac{33.5 - 20}{43 - 20}}$ |
|   | = $250 \times \sqrt{\frac{13.5}{23}}$           |
|   | = $250 \times 0.78$                             |
|   | = 192, say 190 g.p.m.                           |

This is the very minimum adjusted fire flow ever expected at this vicinity.

|   |                   |
|---|-------------------|
| Desired fire flow at 20 psi. residual static pressure | = 1,000 g.p.m.    |
| Deficit assigned to new feeder                        | = 1,000 — 190     |
|   | = 890 g.p.m.      |
| Loss of head  | = 60 — 20         |
|   | = 40 psi.         |
| Loss of head per 100 ft.                              | = $\frac{40}{45}$ |
|   | = 0.89 ft.        |

From Table 11, at 900 g.p.m. and 0.89 ft. loss of head per 100-foot length, a ten-inch pipe is found to be satisfactory. As this table is based on old pipe with some allowance made for impaired capacity, the smaller line may be selected if cement lined or walled, or if the corrosive action of the water is controlled.

It is worth noting that ordinarily outskirts of a town contain low value dwellings widely spaced, so that a fire flow of 500 g.p.m. is commonly ample; this would have taken a smaller pipe than calculated in the problem. Every effort should be made to provide for circulation in dead end feeders where possible; when this cannot be done, an oversized line should be avoided to prevent a long storage period and low velocities.

TABLE 11

Loss of Head, Feet per 100-Foot Length, Caused by Friction  
in Ordinary Cast Iron Pipe, 15-Year Old ( $C = 100$ )

| Flow<br>g.p.m. | Pipe Diameter in Inches |       |       |       |      |      |      |          |
|----------------|-------------------------|-------|-------|-------|------|------|------|----------|
|                | 4                       | 5     | 6     | 8     | 10   | 12   | 14   | 16 18 20 |
| 40             | 0.22                    |       |       |       |      |      |      |          |
| 50             | 0.34                    |       |       |       |      |      |      |          |
| 75             | 0.73                    | 0.24  |       |       |      |      |      |          |
| 100            | 1.22                    | 0.41  | 0.14  |       |      |      |      |          |
| 125            | 1.86                    | 0.64  | 0.28  |       |      |      |      |          |
| 150            | 2.55                    | 0.88  | 0.32  |       |      |      |      |          |
| 175            | 3.44                    | 1.18  | 0.48  |       |      |      |      |          |
| 200            | 4.40                    | 1.48  | 0.62  |       |      |      |      |          |
| 225            | 5.45                    | 1.86  | 0.74  |       |      |      |      |          |
| 250            | 6.72                    | 2.24  | 0.92  | 0.22  |      |      |      |          |
| 275            | 7.99                    | 2.72  | 1.15  | 0.27  |      |      |      |          |
| 300            | 9.30                    | 3.14  | 1.29  | 0.32  |      |      |      |          |
| 350            | 12.32                   | 4.19  | 1.75  | 0.42  |      |      |      |          |
| 400            | 16.00                   | 5.40  | 2.21  | 0.54  |      |      |      |          |
| 450            | 19.80                   | 6.70  | 2.65  | 0.68  | 0.21 |      |      |          |
| 500            | 24.00                   | 8.12  | 3.30  | 0.82  | 0.28 | 0.11 |      |          |
| 550            |                         | 9.60  | 3.93  | 0.97  | 0.33 | 0.14 |      |          |
| 600            |                         | 11.30 | 4.70  | 1.14  | 0.39 | 0.15 |      |          |
| 650            |                         | 13.20 | 5.40  | 1.34  | 0.46 | 0.19 | 0.09 |          |
| 700            |                         | 15.10 | 6.20  | 1.54  | 0.52 | 0.22 | 0.10 |          |
| 750            |                         | 17.20 | 7.00  | 1.74  | 0.59 | 0.24 | 0.11 |          |
| 800            |                         |       | 8.00  | 1.97  | 0.67 | 0.27 | 0.13 |          |
| 850            |                         |       | 8.95  | 2.28  | 0.75 | 0.31 | 0.14 |          |
| 900            |                         |       | 10.11 | 2.46  | 0.83 | 0.34 | 0.16 |          |
| 950            |                         |       | 10.80 | 2.87  | 0.91 | 0.38 | 0.18 |          |
| 1,000          |                         |       | 12.04 | 3.02  | 1.01 | 0.41 | 0.19 |          |
| 1,050          |                         |       | 13.30 | 3.21  | 1.09 | 0.44 | 0.22 |          |
| 1,100          |                         |       | 14.31 | 3.51  | 1.20 | 0.49 | 0.23 |          |
| 1,150          |                         |       | 15.60 | 3.84  | 1.34 | 0.53 | 0.25 |          |
| 1,200          |                         | 16.69 | 4.15  | 1.46  | 0.57 | 0.26 |      |          |
| 1,500          |                         |       | 6.27  | 2.09  | 0.85 | 0.39 | 0.21 |          |
| 2,000          |                         |       | 10.71 | 3.65  | 1.43 | 0.60 | 0.39 | 0.34     |
| 2,500          |                         |       |       | 5.33  | 2.28 | 1.01 | 0.56 | 0.50     |
| 3,000          |                         |       |       | 7.80  | 3.15 | 1.47 | 0.80 | 0.69     |
| 3,500          |                         |       |       | 10.08 | 4.10 | 1.81 | 1.04 | 0.89     |
| 4,000          |                         |       |       |       | 5.32 | 2.47 | 1.34 | 1.12     |
| 4,500          |                         |       |       |       | 6.90 | 3.22 | 1.65 | 1.37     |
| 5,000          |                         |       |       |       | 8.40 | 3.92 | 2.02 | 1.75     |
| 5,500          |                         |       |       |       |      | 4.65 | 2.39 | 1.94     |
| 6,000          |                         |       |       |       |      | 5.50 | 2.60 | 2.25     |
| 6,500          |                         |       |       |       |      | 6.45 | 3.32 | 2.60     |
| 7,000          |                         |       |       |       |      | 7.15 | 3.68 | 2.95     |
| 7,500          |                         |       |       |       |      |      | 4.28 | 3.32     |
| 8,000          |                         |       |       |       |      |      |      | 3.72     |
| 8,500          |                         |       |       |       |      |      |      | 4.13     |
| 9,000          |                         |       |       |       |      |      |      |          |
| 9,500          |                         |       |       |       |      |      |      |          |
| 10,000         |                         |       |       |       |      |      |      |          |

The numerical values have been reprinted by permission from "Hydraulic Tables" by Williams & Hazen, published by John Wiley & Sons, Inc.



Blocked-in areas show range of delivery within which a given diameter transmission line may usually show greatest economy with respect to power costs and fixed charges. In such cases the pressure drop is subject to choice. However, in distribution systems, the pressure drop ordinarily is set by existing conditions and therefore these blocked areas are disregarded.

This table is based on the Williams-Hazen formula; two useful modifications are as follows:

$$\text{Loss of head (ft. per 100 ft.)} = \frac{1,055.3 \times \text{rate of flow}_{\text{g.p.m.}}^{1.85}}{C^{1.85} \times \text{Diameter}_{\text{in.}}^{4.87}}$$

$$\text{Rate of flow (g.p.m.)} = 0.0233 \times C \times \text{Diameter}_{\text{in.}}^{2.63} \times \sqrt{\text{loss of head}_{\text{ft. per 100 ft.}}^{0.54}}$$

**Relative Flow Capacity.** The effect of pipe diameter on friction loss is shown in the approximate formula:

$$h = k \frac{v^2 L}{2gD}$$

in which

$k$  = a quantity, almost constant

$v$  = velocity

$L$  = length

$D$  = diameter

$2g$  = 64.32

$h$  = friction loss

By combining the constants this formula is shortened to:

$$h = \text{Constant} \times \frac{v^2 L}{D}$$

which shows the head loss to vary as the square of the velocity, directly as the length, and inversely as the diameter. Since the discharge ( $Q$ ) is calculated from the product of the cross-sectional area by the velocity, that is:

$$Q = 0.785D^2 \times v$$

then

$$v = \frac{Q}{0.785D^2}$$

Substituting this value for the velocity in the head loss formula:

$$h = \text{Constant} \times \frac{Q^2 L}{0.785^2 D^4 D}$$

which simplifies to:

$$h = \text{Constant}' \times \frac{Q^2 L}{D^5} \quad (A)$$

or

$$Q = \sqrt{\frac{D^5 h}{\text{Constant}' \times L}} \quad (B)$$

These formulas reveal important relationships between friction and pipe size. Formula (A) shows that for a given discharge the friction loss decreases according to the fifth power of the pipe diameter. Thus, if the diameter of a line is doubled, with the discharge remaining fixed, the friction loss is reduced to  $1/2^5 = 1/32$  of the original amount. Similarly, formula (B) shows that if the loss of head due to friction is held constant, the discharge must vary as the five-halves power of the diameter.

A simpler, but less accurate, interpretation is that a small per cent increase in the pipe diameter results in a 5 times relative reduction in head loss. Also a small per cent increase in diameter, with fixed head loss, increases the discharge relatively  $2\frac{1}{2}$  times. These relations emphasize the important influence of pipe diameter on carrying capacity.

The relative flow capacities of smooth pipe of different sizes are shown in Table 12. In long pipe-lines the resistance of the bends and valves may be neglected; when considered in the calculations, their friction loss is expressed in terms of an equivalent length of pipe which is then added directly to the straight runs. As the equivalent length of the various fittings depend on their size, this value can best be determined by means of the nomograph, Figure 33. To use this chart, a straight line is drawn between the proper illustrated point on the fittings scale to the scale of nominal diameter. The equivalent length

of straight pipe, in feet, is read where this line crosses the middle scale.

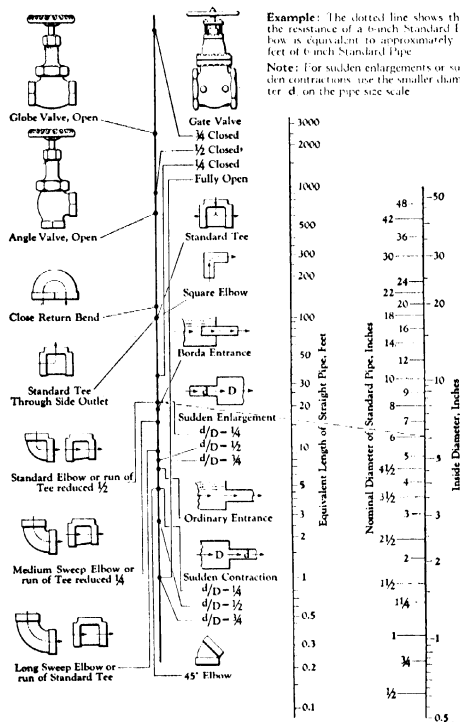


FIGURE 33

Resistance of Valves and Fittings to Flow of Fluids

(Courtesy of Crane Company, Chicago, Ill.)

The number of pipes required to equal the carrying capacity of a larger pipe, with the same loss of head, is proportional to approximately the five-halves power of the ratio of their diameters.

TABLE 12  
Relative Flow Capacities of Smooth Full Pipe

| Diameter<br>Inches | Equivalent Number of Smaller Pipes |      |      |      |     |     |     |     |     |     |    |    |    |    |    |    |    |
|--------------------|------------------------------------|------|------|------|-----|-----|-----|-----|-----|-----|----|----|----|----|----|----|----|
| 1                  | 2                                  | 4    | 6    | 8    | 10  | 12  | 14  | 16  | 18  | 20  | 24 | 30 | 36 | 42 | 48 | 54 | 60 |
| 2                  | 5                                  |      |      |      |     |     |     |     |     |     |    |    |    |    |    |    |    |
| 4                  | 32                                 | 5.7  |      |      |     |     |     |     |     |     |    |    |    |    |    |    |    |
| 6                  | 88.2                               | 15.6 | 2.8  |      |     |     |     |     |     |     |    |    |    |    |    |    |    |
| 8                  | 181                                | 32   | 5.7  | 2.1  |     |     |     |     |     |     |    |    |    |    |    |    |    |
| 10                 | 316                                | 55.9 | 9.9  | 3.6  | 1.7 |     |     |     |     |     |    |    |    |    |    |    |    |
| 12                 | 499                                | 88.2 | 15.6 | 5.7  | 2.8 | 1.6 |     |     |     |     |    |    |    |    |    |    |    |
| 14                 | 733                                | 130  | 22.9 | 8.3  | 4.1 | 2.3 | 1.5 |     |     |     |    |    |    |    |    |    |    |
| 16                 |                                    | 181  | 32   | 11.7 | 5.7 | 3.2 | 2.1 | 1.4 |     |     |    |    |    |    |    |    |    |
| 18                 |                                    | 243  | 43   | 15.6 | 7.6 | 4.3 | 2.8 | 1.9 | 1.3 |     |    |    |    |    |    |    |    |
| 20                 |                                    | 316  | 55.9 | 20.3 | 9.9 | 5.7 | 3.6 | 2.4 | 1.7 | 1.3 |    |    |    |    |    |    |    |

*Example.* One eight-inch pipe (left column) is equivalent in carrying capacity to 32 two-inch lines. Likewise, an eight-inch pipe is sometimes interpreted to provide for approximately 181 one-inch taps, but actually this number may differ widely according to conditions of installation.

This table also may be used to determine the size of a single pipe equivalent to several smaller pipes in parallel by converting all sizes to a common value, say that of the smallest pipe.

*Example.* What size pipe can replace a four-inch, eight-inch and ten-inch combination, all in parallel?

*Solution.* From the table the number of equivalent four-inch pipes involved are  $1 + 9.9 + 15.6 = 26.5$ . Running down the figures in the four-inch column, this value is found to lie between a fourteen- and a sixteen-inch pipe.

During use, a cast-iron pipe loses some carrying capacity due to incrustation with scale or tuberculation by rusting, depending upon the character of the water. Incrustation occurs with unstabilized lime-treated waters but never reaches serious proportions in cold water lines; on the contrary, the pipe metal is effectively protected against rust. Hard untreated supplies may partially clog pipe-lines with scale. With extremely cor-

rosive waters, tuberculations may reduce carrying capacity down to nearly 45% of its original value. The condition of a pipe-line with respect to its friction losses is indicated in the Williams-Hazen formula by the factor "C." To determine the C value for a pipe in the distribution system the pressure drop and rate of flow must be measured accurately and simultaneously. For new cast-iron pipe,  $C = 130$ ; rusting reduces its numerical value. After about 20 years of use with normal waters, C is reduced to about 100. Unseemly low values of C may indicate a closed valve or an air pocket at the high point in a line; this is especially probable when the line can be tested by sections, one of which shows a widely dissimilar C characteristic. In Table 13 is shown how the values of C are related to original carrying capacity and loss of head.

TABLE 13

Relative Carrying Capacity Based on New Pipe

| Williams-Hazen<br>Coefficient                     | C     | *<br>130 120 110 100 90 80 60 40 |       |       |       |       |       |       |  |
|---|-------|----------------------------------|-------|-------|-------|-------|-------|-------|--|
| % discharge for<br>a given head                   | 100.0 | 92.3                             | 84.6  | 76.9  | 69.2  | 61.5  | 46.2  | 30.8  |  |
| Relative loss of<br>head for a<br>given discharge | 1.00  | 1.160                            | 1.362 | 1.625 | 1.972 | 2.455 | 4.180 | 8.850 |  |

\* Typical new value.

*Example.* Find the number of eight-inch pipes whose C value is 90 that are equivalent in flow carrying capacity to a new ten-inch cast-iron pipe ( $C = 130$ ).

*Solution.* From Table 12 one ten-inch pipe is equivalent in flow capacity to 1.7 of eight-inch pipes if both are of equal smoothness, but since their discharge under equal head loss varies as the ratio of C values, the number of eight-inch pipes required will be somewhat greater, thus:

$$\begin{aligned}
 \text{Number of eight-inch pipes} &= 1.7 \times \frac{130}{90} \\
 &= \frac{1.7}{0.692} \\
 &= 2.5
 \end{aligned}$$

When  $C$  is below 90, its value may be restored to around 85% of its value when new, or almost 110. Cleaning is done by means of various flow-propelled go-devils or mechanically drawn cleaning tools. Pipes so restored soon lose their improved flow capacity again unless the water is given suitable anti-corrosion treatment, as discussed in Chapter 12. Periodic flushing of hydrants during night hours scours loose sediment, some rust, iron and manganese deposits, and algae growths.

**Gridiron Tests.** When selecting sizes of feeders combined into a distribution network, the flows are first routed according to the demands at key points in the system, and sizes determined accordingly. At present, the most popular method for analyzing the split up of flows in a complicated network of mains is the Hardy Cross technique. Such a study, made by qualified individuals, is especially useful for planning the effective reinforcing of existing systems.

Two practical methods for searching out weaknesses in an existing system are the water plane survey and the fire flow test. In the water plane survey, static pressures, determined throughout town preferably by recording gages, are corrected to the same reference elevation on a map and contours drawn between points having the same pressures. Low pressure areas are well defined on such a drawing. Reinforcement is needed where the contours pack closely together indicating a rapid drop in pressure. In the fire flow test, a group of four to eight hydrants are opened and the residual static pressure noted at a closed hydrant centrally located within the group. Flow from each open nozzle is determined by means of a special Pitot tube, or from a pressure gage on the closed nozzle or other methods. The flow from the group is totalized and converted to a 20 pound per square inch residual basis. The principle of this calculation is shown in Chapter 17. From the total flow in various areas, the reinforcement desirable is worked out for fire extinguishing needs, industrial demand, and peak domestic requirements. Such flow tests are most significant in the high value

commercial districts, near the heavy industrial users, and at the remote residential areas.

**Usual Pipe Sizes.** Ordinarily in a gridiron arrangement, feeders are spaced about 2,000 feet apart with smaller connecting mains crossing in between. In the business and high value district, mains are not smaller than 8 to 12 inches; in side streets of residential districts four and two-inch lines are commonly laid in loops. However, since a single six-inch main, over 700 feet long, ordinarily can supply sufficient water to only a single 750 g.p.m. pumper, the usual small-size pipe in residential areas is inadequate for fire protection. To provide sufficient flowage for fire protection, four-inch and smaller sizes are ruled out. Six-inch pipe has been recommended by the National Board of Fire Underwriters as the minimum size for residential districts, and then only for blocks not longer than 600 ft. in well connected grids.

Service lines sizes are three-quarter-inch minimum for a single family connection; if longer than 50 feet a one-inch line is used. Apartments, smaller than 25 families, are connected by a two-inch line. Heavy industrial consumers require larger sizes which may be approximately chosen from the friction loss table to meet their particular draught.

**Fire Hydrants.** Placed to secure minimum insurance rates, hydrants are usually installed at street corners and at the middle of blocks in the business district; in residential sections, they are set at street intersections, but not spaced more than 600 feet apart. Two 2½-inch hose nozzles, with one four-inch pumper suction in high value districts, are commonly used. Threads should conform with national standards. Unless a self closing design is adopted, the branch line leading to the hydrant should have a gate valve for closure if the barrel is broken. A small outlet near the bottom of the barrel drains off water into a small gravel pack in order to prevent damage from frost.

Inspections should be at quarterly intervals. The nozzle caps should fit tightly and the drain valve close when the hydrant

is opened. The compression valve shut-off must be complete. A coat of graphited grease should be applied to the nozzle's threads and the caps replaced. The valve stem should be oiled. For more permanent lubrication and protection against corrosion, the working nut and screw in the dome of the hydrant should be covered with a stiff water resistant grease, such as used in automobile water pumps or in wheel bearings. A card record should show the results of each inspection and repair.

Aside from fire protection, hydrants are useful as blow-off valves for flushing mains and as dosing chambers for introducing a charge of hypochlorite powder into the system.

## METERS

**Small Service Meters.** The use of service meters enable an equitable distribution of charges based on the amount of water consumed. Metered supplies always show lower per capita consumption than flat rate systems, therefore, by installing meters into a previously unmetered locality, an overloaded plant can be considerably relieved of unnecessary losses and wastes.

Meters from 5/8 to 2-inch size, are commonly the nutating disc type; its advantages are simplicity, accuracy, low loss of head, easy maintenance and low repair costs. Sensitivity to small flows is reduced in the larger sizes. More accurate, but also more expensive, are the rotating position and the oscillating piston types. All are positive displacement meters. Their accuracy is unaffected by their position in the pipe such as with bends close by. The size of meter selected is usually a size smaller than the service pipe. Oversized meters should be avoided on account of their slippage at low flow.

**Large Meters.** For services larger than two-inch, the compound meter is usually installed as it causes a lower loss of head than does a large disc meter but still retains a high degree of accuracy. Small flows pass through a disc meter in a by-pass, but larger flows open the main port hydraulically so that a large



volume may pass without excessive loss of head. The main flow is registered on a proportional meter, that is, one through which passes a known fraction of the principal stream; however, the dial may be graduated to read total volume directly. Obviously the total consumption equals the sum of the registration of both low and high flow meters. The effect of a compound meter may be obtained in a simple manner on fairly large services by a splitting of the line into two or more branches, in one of which a 5/8-inch disc is connected to register low flows and in the others larger disc meters are inserted behind a 45°-check valve to record only those flows heavy enough to raise the flap.

Current-meters consist of a wheel with blades; this is turned by the velocity of water in the pipe-line and revolutions are registered through a reducing train as in the other types. These meters are used for heavy drafts only as they are not sensitive to low flow. A low loss of head permits their use as a master meter at the pumping station.

**Accuracy of Disc Meters.** The accuracy of the usual open gear 5/8-inch disc meter depends on the rate of flow. Below about 1 g.p.m. the per cent registration falls off rapidly; a slight over-registration is usually found between 1 to 5 g.p.m.; at higher rates the accuracy slowly levels off to reach about 98% at the high use rate around 20 g.p.m. In adjusting a meter, the aim is to balance over- and under-registration so that a fair 100% average is struck for normal conditions of use. Gears should be selected to give 98 to 98½% registration at 12 g.p.m. The disc should fit closely enough to show 98% accuracy at ¾ g.p.m. and about 90% at ¼ g.p.m. A test should show the dead meter breakaway point near 0.07 g.p.m. (100 g.p.d.). About 85% of the average one-family consumption is below a 5 g.p.m. rate; therefore, low rate accuracy is especially to be watched.

A testing device should be used which allows testing at known, indicated rates rather than to rely on a certain size

test orifice, since this latter method depends on the pressure at the time of test. The  $\frac{1}{4}$  g.p.m. rate, usually expected from the  $\frac{1}{32}$ -inch orifice, may be conveniently checked by noting the time taken to fill a quart milk bottle. One effective arrangement is the combination of a rotameter in series with the meter nest on a test bench. Residential meters are not checked, unless on complaint, except at intervals of five years or longer, depending upon the characteristics of the water. Meters larger than two inches are tested annually. Inner parts may be cleaned by soaking 10 minutes in hot trisodium phosphate solution (0.3 lb. per gallon), then dipping successively into a water wash, 1:1 nitric acid, a water wash, 1:1 sulfuric acid, a water wash, and finally a hot water rinse to hasten drying. Repairs are guided by feel and blowing through the disc chamber, rather than by gages. After making repairs, restoring worn parts, and cleaning, a test should be run before replacing the meter in service, and results recorded in a card file. A hypochlorite solution, 10 to 50 p.p.m. available chlorine, is passed through the meter and the openings capped prior to sending out after reconditioning. Rebuilt meters are accepted by consumers with greater confidence when repainted before installation.

Gross inaccuracies may be revealed by field tests. One procedure is to fill a five-gallon can from a residential hydrant and note the readings. Another method consists in attaching a calibrated meter to an outside hydrant through a hose and note the readings on each meter after a short test run. Leakage in the household plumbing may be allowed for, where found, by noting the rate of motion of the service meter pointer and adding a proportionate amount to the reading of the standard meter.

## HAZARDOUS CONNECTIONS

A cross-connection linking a potable supply with a source of questionable or unsafe water is a pollution hazard which should

be eliminated by installing only approved piping arrangements. Cross-connections may be divided into two broad types: direct cross-connections, and conditions allowing back-siphonage. Direct cross-connections may allow water from a high pressure source to force entrance directly into the domestic supply, particularly during periods of low pressure in the mains. Back-siphonage occurs through submerged inlets to tanks and fixtures when a partial vacuum, or a so-called negative pressure in the water piping sucks back the unsafe liquid and so contaminates the potable supply.

**Cross-Connections.** Some typical cross-connections include the following:

1. A bottom inlet supplying city water to an elevated tank which may also receive water from other sources, as in Figure 34 (a).

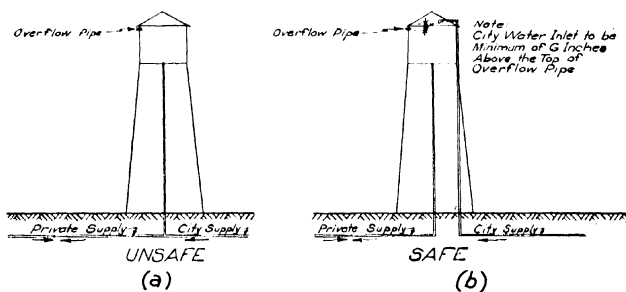


FIGURE 34

Unsafe and Safe Connection (Cross-Connection) between a City Water and a Private Supply in a Tower Tank

(Courtesy of Louisiana State Department of Health, Division of Public Health Engineering)

If city pressure drops, the tank elevation causes its contents to move back into the distribution system. Safe practice requires that the city water riser be outside the tank and discharge above the overflow level as shown in Figure 34 (b).

2. A tee-connection permitting a choice of city water or

questionable private supply in plant equipment, such as Figure 35 (a).

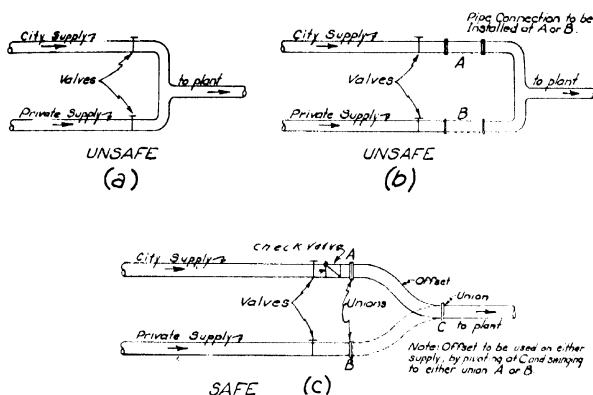


FIGURE 35

Unsafe and Safe Connection (Cross-Connection) between a City Water and a Private Supply Connected to an Industrial Plant Line

(Courtesy of Louisiana State Department of Health, Division of Public Health Engineering)

Fire protection systems and emergency cooling water connections, in the past, have been cross-connected in this manner. The two gate valves shown are not sufficient protection because a higher pressure in the private supply can force unsafe water through any slight leak in the valve on the public supply, or, through the opened valve if both valves are opened accidentally at the same time. Valves and checks are never considered as absolute protection. A double check valve is sometimes allowed to protect a cross-connection in special circumstances under Department of Health approval. Preferably all bronze, these valves should be installed between two gate valves to permit access for annual inspection and cleaning.

The approved connection for an emergency choice of services

under pressure consists of a swing joint with loose elbows, unions, or a ball and socket joint. In Figure 35 (c) a check valve, or better yet a vacuum breaker, is placed in the city water line to prevent backflow of water from the possibly contaminated piping in the plant in case city pressure should fail. City water may also be fed through a vented elevated tank which is filled from an inlet whose bottom is at least six inches above the overflow level. An automatic hydraulic valve and perforated shift-pipe combination, termed an Interconnector, has recently been offered for positive and foolproof choice of supply from dual sources. Several other types of automatic protective devices, with ports opening to atmosphere between connections to alternate sources of water supply under pressure, are now available for industrial consumers who require quick access to the municipal supply in emergencies.

3. Priming lines and some sealing water lines to pumps handling unsafe liquids.

If the city water valve leaks, then pump pressure forces the unsafe liquid into the potable supply. Pumps should be primed from an open tank, fed from overhead through a float valve with a six-inch air gap as described above. A small motor driven pump may then furnish sealing water to the pump lantern ring.

Since cross-connections involve direct physical contact between supplies, a quick method for their location, sometimes useful, is to test the two piping systems electrically by applying voltage to one pipe and noting if current to ground may be obtained through the other.

**Back-Siphonage.** Back-siphonage is permitted by various unprotected applications of a submerged city water inlet into a fixture whenever a vacuum forms in the house plumbing or distribution systems. A partial vacuum may be produced by the following conditions:

- a. Interruption in the city service.
- b. Draining off plumbing during repairs or through a stop and waste cock.

- c. Heavy draft from fire engines.
- d. Operation of a large booster pump in the neighborhood.
- e. Too many lower floor outlets and undersize piping in apartments and buildings.

Badly tuberculated piping is also dangerous by restricting the flow capacity.

Submerged inlets to tanks and below-the-rim faucets in fixtures are forbidden in most states by the Sanitary Code. An overhead inlet should not approach closer than  $1\frac{1}{2}$  pipe diameters to the water surface because then back suction can draw up water through the air in a conical crater to the inlet opening. When bottom inlets must be used, backflow may be prevented by means of an approved type of vacuum breaker, placed on the fixture side of the valve and installed at a high point to avoid flooding. A special disconnect joint, which requires manual pressure by the operator for seating, is also used in such cases as flush-out lines for cleaning sewage meters. An overhead submerged feed line cannot form a vacuum if its high point is teed open to the atmosphere. A check valve or vacuum breaker may be placed in the air limb of the tee. A high loop, over 32 feet, will prevent backflow since a vacuum cannot draw water higher. If any chance exists to build up pressure in a high protective loop, a pressure relief valve may be installed in approved situations. Back-siphonage is commonly prevented at swimming pools by feeding city water through an open elevated tank with a six-inch clearance between rim and overhead float-controlled inlet.

Back-siphonage is also physically possible into equipment directly connected to potable water when *outlets* are not separated by an air gap from a drain or sewer connection. If the sewer line is stopped up and a vacuum occurs simultaneously in the water system, waste will be drawn back through the unprotected equipment.

## CHAPTER 17

# HYDRAULIC MEASUREMENT DEVICES

ALTHOUGH some form of mechanical meter is the most convenient means with which to measure flow of water, this equipment cannot meter large flows directly, such as those pumped by large towns. Consequently, other and simpler methods must be used for large pipe-line measurements. Occasionally situations occur, like testing a new well, where measurement is greatly simplified by using a fundamental hydraulic method, especially when there is no large mechanical meter at hand. Hydraulic measuring devices described below are the (a) orifice, (b) venturi meter, (c) pitot tube, (d) weir and (e) proportional meter. Other methods of measurement are available but their application in water systems is infrequent.

### ORIFICE

The sharp-edged orifice, illustrated in Figure 36, is the easiest and cheapest of all hydraulic devices to prepare for measuring the velocity and volume of water passing through a pipe. A thin plate with a beveled hole in the center is bolted between the flanges with the sharp edge pointing upstream. The orifice diameter should be within 0.10 to 0.75 of the pipe diameter. The resistance due to this partial obstruction causes a drop in pressure which varies with the rate of flow. Pressure readings are taken by altitude gages or water columns at taps located two pipe diameters upstream and one-half pipe diameter downstream from the orifice. The taps should be set flush with the inside surface, otherwise readings will be inaccurate. Under these conditions the velocity of flow ( $v$ ) in feet per second

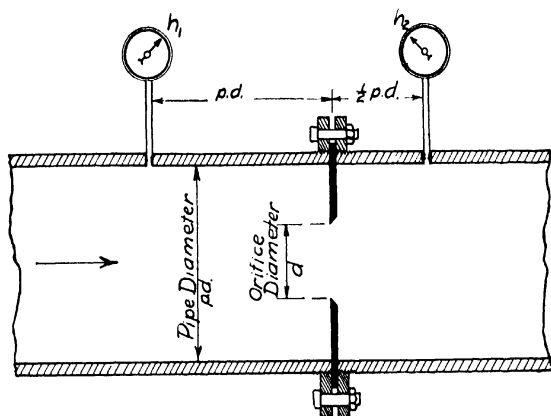


FIGURE 36

Sharp-Edged Orifice

(ft./sec.) through the sharp edge of the orifice depends only on the difference in pressure readings according to the relation:

$$v = C \sqrt{2g(h_1 - h_2)}$$

where:  $C$  = a constant whose value is 0.61 for the orifice as described. This in effect measures the efficiency of the flow through the opening.

$g$  = acceleration due to gravity, namely 32.16 ft./sec.<sup>2</sup>

$$\sqrt{2g} = 8.016$$

$h_1$  and  $h_2$  = pressure readings, in feet of water, on taps as shown in Figure 36.

Simplifying:

$$v = 4.89\sqrt{h_1 - h_2}$$

The square root sign  $\sqrt{\quad}$  indicates that a number must be used whose square equals the quantity under the sign. A chart from which square roots may be obtained conveniently is given in Figure 49.



The amount of water flowing ( $q$ ) in cubic feet per second (ft.<sup>3</sup>/sec.) is equal to the velocity of the stream in feet per second (ft./sec.) times the area of the orifice in square feet (sq. ft.)

$$\begin{aligned} q &= 4.89\sqrt{h_1 - h_2} \times \text{area} \\ &= 4.89\sqrt{h_1 - h_2} \times 0.785d^2 \end{aligned}$$

where:

$d$  = diameter of orifice in feet

then,

$$q = 3.84d^2\sqrt{h_1 - h_2}$$

If the rate of flow is to be expressed in gallons per minute (g.p.m.) and the orifice diameter is measured in inches, the formula for an orifice becomes:

$$Q \text{ (g.p.m.)} = 12.0D_{\text{inches}}^2 \sqrt{h_1 - h_{2\text{ft. water}}}$$

An orifice is easily made and quickly installed in any pipe-line. Its main drawback is that an appreciable part of the pressure difference is not recoverable and so causes an added energy loss in pumping.

When the orifice is placed on the end of a pipe-line to measure the discharge out into the atmosphere, only the upstream pressure gage is needed since the downstream gage pressure is zero. The formula then becomes:

$$Q \text{ (g.p.m.)} = 12.0D_{\text{inches}}^2 \sqrt{h_{1\text{ft. water}}}$$

*Example.* Water flowing through a 4-inch sharp-edged orifice in a 10-inch pipe causes pressure gage readings of 120 ft. and 105 ft. upstream and downstream, respectively. What is the rate of flow in g.p.m.?

#### Calculation

$$\begin{aligned} \text{Differential head, ft. water} &= 120 \text{ ft.} - 105 \text{ ft.} \\ &= 15 \text{ ft.} \end{aligned}$$

$$\begin{aligned} Q \text{ (g.p.m.)} &= 12.0D_{\text{inches}}^2 \sqrt{h_{\text{ft. water}}} \\ &= 12.0 \times 4^2 \times \sqrt{15} \\ &= 12.0 \times 16 \times 3.87 \\ &= 743 \text{ g.p.m.} \end{aligned}$$

**Fire Plug Nozzle.** If instead of a sharp-edged orifice at the tip of a pipe, a machined nozzle is placed there, almost the same type of formula applies but a much higher value for the constant must be used for calculation, since a tapered smooth bore delivers its stream with only slight friction loss. Flow through a short tube follows an intermediate pattern between that of a smooth nozzle and a sharp edged orifice. A frequently used case conforming to a short tube is the free discharge through a fire hydrant nozzle as during a fire underwriter's test for flow capacity. A pressure gage is first screwed to the capped outlet of the fire plug and the other nozzle allowed to flow wide open. The flow is calculated from the formula:

$$Q \text{ (g.p.m.)} = 27D_{\text{inches}}^2 \sqrt{\text{Pressure}_{\text{psi}}}$$

which is based on an orifice coefficient of 0.90.

*Example.* In measuring the discharge from a fire hydrant, the pressure at the closed nozzle was 25 psi. as the stream spouted from the open 2½-inch nozzle. Calculate the discharge in g.p.m.

$$\begin{aligned} \text{Calculation. Discharge (g.p.m.)} &= 27D_{\text{inches}}^2 \sqrt{\text{Pressure}_{\text{psi}}} \\ &= 27 \times 2.5^2 \times \sqrt{25} \\ &= 27 \times 6.25 \times 5 \\ &= 844 \text{ g.p.m.} \end{aligned}$$

Instead of reading the hydrant pressure, the face of the gage may be calibrated, according to the above formula, to show the discharge directly, as in Figure 37 which shows such a device for use with a 2½-inch nozzle. This drawing may also be used to obtain an approximate solution to the above calculation. The accuracy of the pressure gage should be checked on a cold test apparatus, especially in the low pressure range below 500 g.p.m. flow where slight inaccuracy causes relatively large errors in the indicated discharge. For flows below 250 g.p.m. an ordinary pressure gage of the type illustrated here fails to deflect. Such low flows may be determined

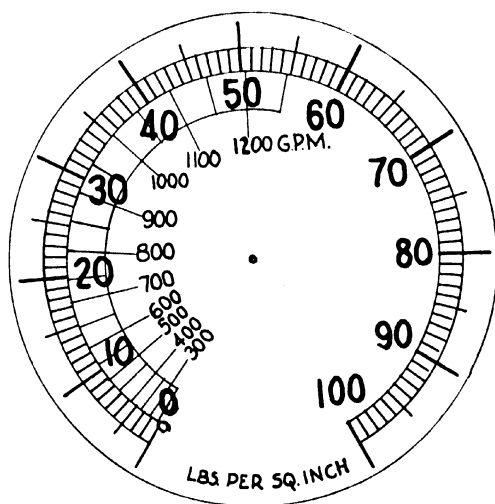


FIGURE 37

Calibration of Pressure Gage to Read Flow Directly from  
2½-Inch Fire Hydrant Nozzle

(Courtesy of *Water Works & Sewerage*)

by timing the flow through a short hose into a barrel. Use of 4 or 4½-inch nozzles is not recommended for measuring fire flows since the results are not so accurate.

**Trajectory Method.** Lower flows than 250 g.p.m. from a fire hydrant may be measured approximately either by use of a more sensitive gage than that shown in Figure 37, or by means of a rule to determine the trajectory, or projection of the stream out from the tip of the nozzle. As illustrated in Figure 38 the distance is measured out to the bottom of the jet at a point where it has dropped 1 foot below the invert of the nozzle; the corresponding discharge is then read from a previously established calibration curve. If much work of this sort is planned, the rate of flow may be marked directly on

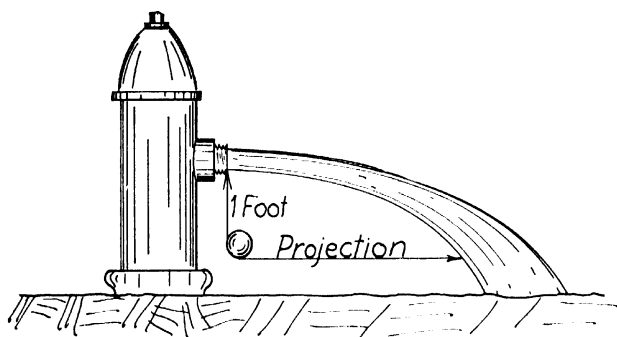


FIGURE 38

Trajectory Method for Measuring Small Flows from a Fire Hydrant

the offset rule. Such a rule divided to indicate directly the discharge from a typical  $2\frac{1}{2}$ -inch nozzle is shown in Figure 39.

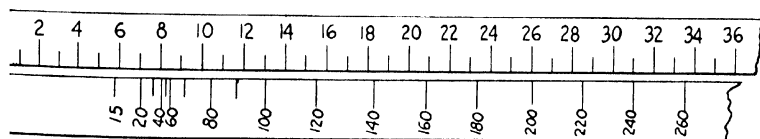


FIGURE 39

Ruling of Trajectory Scale for  $2\frac{1}{2}$ -Inch Fire Hydrant Nozzle

Below about 65 g.p.m., where the nozzle does not flow full, the divisions are spaced differently than for higher flows.

**Fire Flow Tests.** Available fire flows are determined by measuring the discharges from a group of hydrants, not over six, such as would be opened during a fire, and calculating the total flow to a residual static pressure of 10 or 20 psi. The static pressure is read at a centrally located hydrant kept closed during the test; an open hydrant cannot be used for this purpose due to the appreciable friction loss through the connections and barrel when flowing. Adjustment to a 20 psi. basis is made by

multiplying the observed flow by the square root of the ratio of the allowable pressure drop to the actual pressure drop.

*Example.* Flows measured within a group of four fire hydrants were 844, 500, 400 and 350 g.p.m. respectively, while the static pressure at a central closed hydrant was 25 psi. Before and after the test, with all hydrants closed, this hydrant read 70 psi. What is the available fire flow at 20 psi. residual pressure?

*Calculation.* Total observed flow. =  $844 + 500 + 400 + 350$   
= 2094 g.p.m.

Discharge adjusted to  
20 psi. residual pressure =  $2094 \times \sqrt{\frac{70 - 20}{70 - 25}}$   
=  $2094 \times 1.054$   
= 2207 g.p.m.

Fire flow requirements of the National Board of Fire Underwriters are tabulated on page 7.

### VENTURI METER

The venturi meter consists of a reduced pipe section with a tapered approach and expanding tail piece, as illustrated in

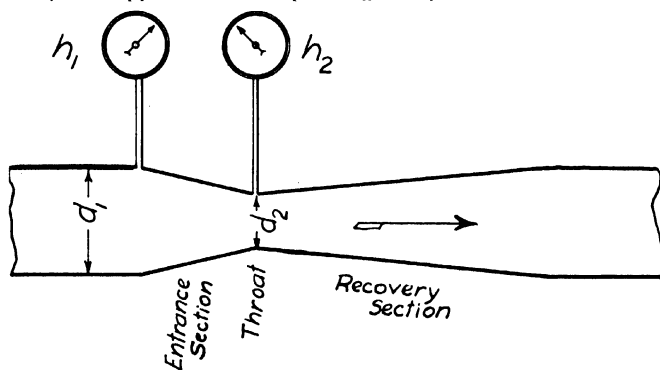


FIGURE 40  
Venturi Meter

Figure 40. This device is widely used to meter large flows; and also to operate filter controllers. Its advantages include simplicity, reliability, ruggedness, freedom from clogging, accuracy, and very small permanent loss of head. Pressure gages or some form of manometer tubes are connected to the approach and throat sections. As in the orifice, the rate of flow varies with the square root of the difference in pressure readings. The following formula may be used in calculating the discharge through a venturi meter:

$$Q \text{ (g.p.m.)} = 2821 C \sqrt{\frac{d_1^4 d_2^4}{d_1^4 - d_2^4}} \sqrt{h_1 - h_2}$$

$C$  is a constant for a given venturi, as furnished by the manufacturer or determined by previous test, or calibration; its value is usually well above 0.95. The diameters and heads should be expressed in feet. With a given venturi, all numbers may be condensed into a single value,  $K$ , so that future calculations need not follow through the long formula.

$$Q \text{ (g.p.m.)} = K \sqrt{h_1 - h_2}$$

*Example.* A 6-inch venturi is installed in an 8-inch pipe-line. Assuming  $C = 0.98$ , first find the value of  $K$ , then calculate the flow when the altitude gages read 120 and 116 feet, respectively.

*Calculation.* Diameters  $\begin{cases} d_1 = 8/12 = 0.67 \text{ ft.} \\ d_2 = 6/12 = 0.50 \text{ ft.} \end{cases}$

$$\begin{aligned} K &= 2821 \times 0.98 \times \sqrt{\frac{0.50^4 \times 0.67^4}{0.67^4 - 0.50^4}} \\ &= 2765 \times \sqrt{\frac{0.0625 \times 0.2013}{0.2013 - 0.0625}} \\ &= 2765 \sqrt{\frac{0.01259}{0.1388}} \\ &= 2765 \times 0.301 \\ &= 843 \end{aligned}$$

$$\begin{aligned}
 Q \text{ (g.p.m.)} &= K\sqrt{h_1 - h_2} \\
 &= 843\sqrt{120 - 116} \\
 &= 843\sqrt{4} \\
 &= 1686 \text{ g.p.m.}
 \end{aligned}$$

### PITOT TUBE

The pitot tube is a set of tubes which measure directly the so-called velocity head causing flow past a given section of pipe. Two pressure readings are taken, as illustrated in Figure 41,

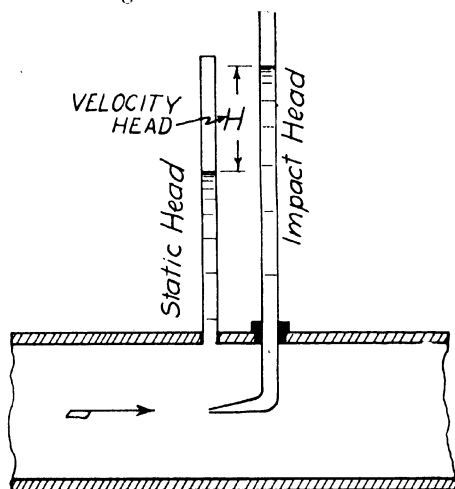


FIGURE 41

Pitot Tube

one from a tap flush with the wall and the other from a connection pointing upstream to catch the impact of the current. In commercial tubes, these parts are telescoped together for compactness. Pitot tubes are used when an economical device, that does not cause added head loss, is desired. Being portable,

this method is widely used for distribution system surveys. The velocity ( $v$ ) in feet per second (ft./sec.) past the point of the bent tip is simply:

$$\begin{aligned} v \text{ (ft./sec.)} &= \sqrt{2gh} \\ &= 8.016\sqrt{h} \end{aligned}$$

The differential head ( $h$ ) is measured in feet. As the velocity varies continuously inside a pipe section from the wall to the center, a complete traverse across the pipe is ordinarily required in order to determine an effective average differential. To allow motion, the instrument is inserted through a stuffing box, and moved across a diameter in order to obtain readings for computing the average velocity. If the pipe length is at least 50 times its diameter and the flow, in g.p.m., numerically exceeds one-third of the diameter, in inches, the average velocity has been found to be approximately 83% of the central velocity. Hence a pitot tube for permanent installation is usually placed with its impact tip at the center of the pipe, and the flow is computed from the relation:

$$Q \text{ (g.p.m.)} = 16.26 D_{\text{inches}}^2 \sqrt{h_{\text{feet}}}$$

*Example.* A pitot tube, inserted in the center of a 6-inch main, gave a differential head reading of 0.4 feet of water. What was the flow?

$$\begin{aligned} \text{Calculation.} \quad Q \text{ (g.p.m.)} &= 16.26 \times 6^2 \times \sqrt{0.4} \\ &= 16.26 \times 36 \times 0.632 \\ &= 370 \text{ g.p.m.} \end{aligned}$$

## WEIR

A weir is a notch, in the side of a box-like vessel, through which water can discharge, as in Figure 42. The water flowing over the sill, per foot of width, depends only on the head ( $h$ ), measured from the sharp edge of the sill to the undisturbed water level further back in the box. Such a simple and readily made device is often used to measure the delivery from a newly



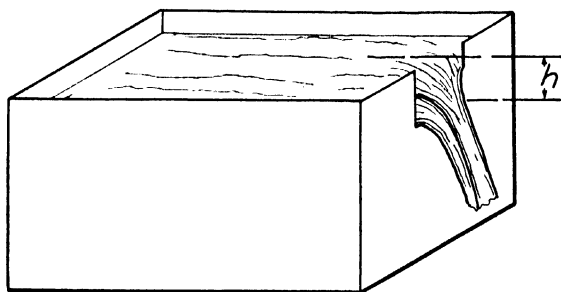


FIGURE 42

## Weir

drilled well. It is also used to measure flow in open ditches and small streams. If the sides are vertical and the edges sharp, the flow ( $q$ ) in cubic feet per second per foot width of sill is given by the formula:

$$q \text{ (cu. ft./sec.)} = 3.33 h^{3/2}$$

The head ( $h$ ) is expressed in feet. If the flow is stated in g.p.m. and the head measured in inches, then the discharge ( $Q$ ) per foot of width becomes:

$$Q \text{ (g.p.m. per ft. width)} = 35.94 H_{\text{inches}}^{3/2}$$

The  $3/2$  power of the head, which is simply the cube of the square root, may be obtained directly from hydraulic tables or calculated in a variety of ways. A direct reading chart for three-halves powers is given in Figure 49.

In the weir illustrated in Figure 42, the stream contracts as it issues past the sharp notch; this effect reduces the true width by an amount equal to 0.1 times the head. If the notch extended the full width of the channel or box, these end contractions would be absent and this correction would not apply. Other types of weirs, having triangular, trapezoidal, parabolic and other special notches, are used for certain applications.

*Example.* Water from a new well is discharged into a large weir box having a 10-inch sharp-edged rectangular notch. What is the flow from the well if the head over the sill is 3 inches?

*Calculation*

$$\begin{aligned}\text{Two end contractions} &= 2 \times 0.1 \times 3 \\ &= 0.6 \text{ inches}\end{aligned}$$

$$\begin{aligned}\text{Effective width of weir} &= 10 - 0.6 \\ &= 9.4 \text{ inches}\end{aligned}$$

$$\begin{aligned}\text{Discharge, g.p.m.} &= 35.94 \times \frac{9.4}{12} \times 3^{3/2} \\ &= 28.18 \times \sqrt{3} \times \sqrt{3} \times \sqrt{3} \\ &= 28.18 \times 1.734 \times 1.734 \times 1.734 \\ &= 146.7 \text{ g.p.m.}\end{aligned}$$

## PROPORTIONAL METERS

Large flows may sometimes be measured quite conveniently by metering a small known fraction, which value is multiplied by a suitable factor, rather than by metering the entire flow. The device used to meter the small measured fraction may be any method applicable to pipe-lines. A handy system is shown in Figure 43 in which a sensitive disc meter is used in the

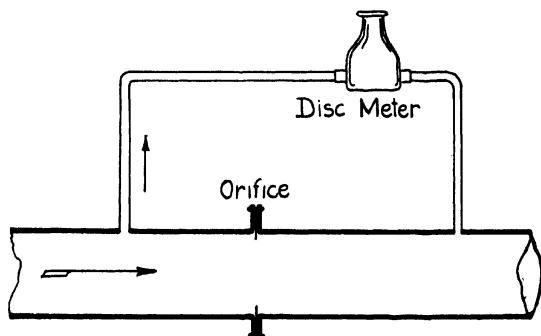


FIGURE 43

Proportional Meter

small branch and a small obstacle is placed in the larger line to cause a definite flow through the meter. The multiplier for the meter reading must be known. This may be calculated if the frictional characteristics of the two paths are known, but generally the factor is obtained by direct test, or calibration.

### OTHER MEASURING DEVICES

Other methods for measurement of water in large flows are mentioned by name only; further descriptions may be found in hydraulic textbooks or in specialized publications. Such devices are the Parshall flume, Kennison nozzle, current meter, friction loss in conduits, differential pressure across a bend, flow nozzle, orifice bucket, Bentzel tube, rotameter, hydraulic pendulum, and other means.

## SECTION 5. CONTROL TESTS

### CHAPTER 18

#### PLANT ARITHMETIC

OPERATORS at water plants should be able to make the following types of calculations in connection with routine management, record keeping and planning. Common problems involve calculations of areas, volumes, rates of flow, dosage, pressure, and power. Simple hydraulic formulas also are used to calculate flow in cases where dial meters are not installed.

#### AREAS

By area is meant the extent of surface exposed within the boundary of a figure. The common unit of area is the square foot. Two kinds of simple figures are important in water plant structures, namely the rectangle and the circle.

**Rectangle.** Most basins, tanks, reservoirs and filters are rectangular in plan, therefore, the rectangle is the most frequently occurring figure whose area must be calculated. The number of square feet in a rectangle is obtained simply by multiplying the length by the width, both dimensions being in feet. This relation may be concisely written as a formula:

$$\text{Area of rectangle (sq. ft.)} = \text{length (ft.)} \times \text{width (ft.)}$$

*Example.* How many square feet of filter area are provided in a sand bed measuring 12 feet long by 10 feet wide?

$$\begin{aligned} \text{Calculation.} \quad \text{Area (sq. ft.)} &= 12 \text{ ft.} \times 10 \text{ ft.} \\ &= 120 \text{ sq. ft.} \end{aligned}$$

**Square.** In the special case where the length and width of the rectangle are equal, the figure is known as a square. The area of a square may be calculated from the formula for a rectangle as above, but since the length and width are equal, the formula may be simplified to read:

$$\begin{aligned}\text{Area of Square (sq. ft.)} &= \text{length (ft.)} \times \text{length (ft.)} \\ &= \text{length}_{\text{feet}}^2\end{aligned}$$

As the length is multiplied by itself, the above statement is further simplified in the second line by writing the figure 2 in the elevated position to indicate that the length appears twice as a factor. In this position the 2 is known as an exponent. Also, since multiplying a number by itself is involved in determining the area of a square, this operation is called *squaring*.

*Example.* Find the surface area of a square basin measuring 50 feet on each side.

$$\begin{aligned}\text{Calculation.} \quad \text{Area (sq. ft.)} &= 50^2 \\ &= 50 \text{ ft.} \times 50 \text{ ft.} \\ &= 2500 \text{ sq. ft.}\end{aligned}$$

**Circle.** Another important and commonly occurring outline is the circle. Pipe-lines and most elevated tanks are circular in section; ground storage reservoirs and filters are frequently circular. By definition, the length around the rim of a circle is called its circumference and the straight line completely across, through the center, is called its diameter. The distance from the center of the circle to its circumference is termed the radius. The length of the circumference is always equal to 3.1416 or roughly  $3 \frac{1}{7}$  times the diameter. This number is commonly denoted by the Greek character  $\pi$ , called pi. To calculate the area of a circle multiply the square of the radius by the number  $\pi$ . Thus:

$$\text{Area of circle (sq. ft.)} = \pi \times \text{radius}_{\text{feet}}^2$$

Since the radius is equal to half the diameter, this formula may also be written in a more workable form:

$$\begin{aligned}
 \text{Area of circle (sq. ft.)} &= \pi \times \left( \frac{\text{diameter}_{\text{feet}}}{2} \right)^2 \\
 &= \frac{3.1416}{4} \times \text{diameter}_{\text{feet}}^2 \\
 &= 0.785 \times \text{diameter}_{\text{feet}}^2
 \end{aligned}$$

This formula may be interpreted to mean that the area of a circle is 78.5% the area of a square whose side equals the diameter of the circle.

*Example.* How many square feet does the cross-sectional area of a 24-inch pipe contain?

$$\begin{aligned}
 \text{Calculation.} \quad \text{Diameter} &= 2 \text{ ft.} \\
 \text{Area, sq. ft.} &= 0.785 \times 2^2 \\
 &= 3.140 \text{ sq. ft.}
 \end{aligned}$$

## VOLUMES

By volume is meant the amount of space or bulk contained within a body. The common unit of volume is the cubic foot. Important shapes to a water plant operator are the rectangular prism and the cylinder. Some other special shapes of common occurrence will be considered briefly.

**Rectangular Tank.** The majority of mixing basins, settling reservoirs, and storage reservoirs are rectangular prisms, or simply rectangular tanks. Their volume, in cubic feet, is calculated by multiplying together all three dimensions, each stated in feet.

$$\text{Volume of rectangular tank (cu. ft.)} = \text{length (ft.)} \times \text{width (ft.)} \times \text{height (ft.)}$$

*Example.* How many cubic feet does a rectangular storage reservoir 30-feet long by 15-feet wide by 10-feet high hold? State answer also in gallons.

$$\begin{aligned}
 \text{Calculation. Volume (cu. ft.)} &= 30 \text{ ft.} \times 15 \text{ ft.} \times 10 \text{ ft.} \\
 &= 4500 \text{ cu. ft.} \\
 \text{Since each cubic foot contains 7.48 (or 7.5) gallons (gal.)} \\
 \text{volume (gal.)} &= 7.5 \times 4500 \text{ cu. ft.} \\
 &= 33,750 \text{ gals.}
 \end{aligned}$$

**Cube.** In the special case where the length, width, and height of a rectangular prism are all equal, this shape is known as a cube. The volume of a cube may be figured by means of the formula for a rectangular tank, but as the dimensions are all alike, the formula may be simplified to:

$$\begin{aligned}\text{Volume of cube (cu. ft.)} &= \text{length (ft.)} \times \text{length (ft.)} \times \\ &\quad \text{length (ft.)} \\ &= \text{length}_{\text{feet}}^3\end{aligned}$$

In the statement on the second line, the figure 3 in the elevated position indicates that the length appears three times as a factor. That is, in the case of a cube the exponent is 3. Since multiplying a number by itself three times is involved in determining the volume of a cube, this operation is called *cubing*.

*Example.* Find how many cubic feet will be held in a cubical tank measuring 15 feet along each edge.

$$\begin{aligned}\text{Calculation. Volume (cu. ft.)} &= 15^3 \\ &= 15 \text{ ft.} \times 15 \text{ ft.} \times 15 \text{ ft.} \\ &= 3,375 \text{ cu. ft.}\end{aligned}$$

**Cylinders.** The cylinder is a very important shape in water-works' structures. Pipe-lines and most elevated tanks are cylinders; many reservoirs and filters are built in cylindrical shape. The volume of a cylinder, in cubic feet, is equal to its cross-sectional area, or area of its base, in square feet, multiplied by its height, in feet. Since the cross section is circular, the formula for a circle must be applied to calculate this area, as shown in the formula below:

$$\begin{aligned}\text{Volume of cylinder (cu. ft.)} &= \text{circular cross-section (sq. ft.)} \\ &\quad \times \text{height (ft.)} \\ &= 0.785 \times \text{diameter}_{\text{feet}}^2 \times \text{height (ft.)}\end{aligned}$$

*Example.* What is the volume of an elevated tank 10 feet in diameter by 15 feet high? State answer in cubic feet and in gallons.

*Calculation*

$$\begin{aligned}
 \text{Volume (cu. ft.)} &= 0.785 \times 10 \text{ ft.} \times 10 \text{ ft.} \times 15 \text{ ft.} \\
 &= 1,177.5 \text{ cu. ft.} \\
 \text{since } 1 \text{ cu. ft.} &= 7.5 \text{ gallons} \\
 \text{volume, (gal.)} &= 7.5 \times 1,177.5 \\
 &= 8,831 \text{ gal.}
 \end{aligned}$$

*Example.* How many gallons will 1 mile of 10-inch pipe hold?

$$\begin{aligned}
 \text{Calculation.} \quad \text{Diameter of pipe} &= 10/12 \text{ ft.} \\
 \text{Length of pipe} &= 1 \text{ mile} = 5,280 \text{ ft.}
 \end{aligned}$$

$$\begin{aligned}
 \text{volume (gal.)} &= 7.5 \times 0.785 \times 10/12 \times 10/12 \times 5,280 \\
 &= 21,590 \text{ gal.}
 \end{aligned}$$

**Short Cut.** The volume of a pipe-line may be estimated by a short-cut method based on the fact that a pipe size of 24.4 inches (take 24 or 25 inches, whichever figure simplifies the calculations) holds a like number of gallons per foot of length, namely 24.4 gallons per foot. Also included are the relations that for a pipe-line the volume varies with the square of the diameter and with the length. Stating these principles in a formula gives:

$$\text{volume (gal.)} = \left( \frac{\text{Diameter}_{\text{inches}}}{24 \text{ or } 25} \right)^2 \times (24 \text{ or } 25) \times \text{length (ft.)}$$

*Example.* Apply the short-cut method to figure approximately the gallons in the pipe-line of the previous problem.

$$\begin{aligned}
 \text{Calculation.} \quad \text{volume (gal.)} &= \left( \frac{10}{25} \right)^2 \times 25 \times 5280 \\
 &= \left( \frac{2}{5} \right)^2 \times 25 \times 5280 \\
 &= 4 \times 5280 \\
 &= 21,120 \text{ gal.}
 \end{aligned}$$

This value is sufficiently close to the correct answer to serve many practical purposes. If 24.4 inches were used for the



constant, the answer would more nearly agree with the correct value.

**Special Shapes.** Occasionally, the volume of a more complicated shape must be calculated. In this class is included the bottom portion of elevated tanks, common shapes being spherical, conical and more complicated dished sections. When the bottom is half of a sphere, or hemispherical, its contents may be calculated by means of the formula:

$$\text{Hemispherical volume (cu. ft.)} = \frac{1}{12} \pi \times \text{diameter}_{\text{feet}}^3$$

When the bottom is an inverted cone, its volume is calculated by the formula:

$$\text{Conical volume (cu. ft.)} = \frac{1}{3} \text{ area of base (sq. ft.)} \times \text{altitude (ft.)}$$

Whereas formulas for dished bottoms and less regular shapes may be used, the calculations become difficult and the volume, in many cases, may be more conveniently determined by direct calibration, that is, by emptying into or filling from a vessel whose volume is known or readily ascertained.

## RATES OF FLOW

**Flow Rate Conversion.** When dealing with pump capacity and plant output, rates of flow are commonly expressed in terms of gallons per minute (g.p.m.) and million gallons per day (MGD). In measuring flow of streams the usual unit is the second foot, as the cubic foot per second (c.f.s.) unit is called.

Since a day consists of  $60 \times 24 = 1,440$  minutes, a gallon per minute is equivalent to 1,440 gallons per day. A million gallons per day equals  $\frac{1,000,000}{1440} = 694$  gallons per minute, or nearly 700 g.p.m. Hence:

$$\begin{aligned} 1 \text{ MGD} &= 694 \text{ g.p.m. (or 700 g.p.m. approximately)} \\ 1 \text{ g.p.m.} &= 0.00144 \text{ MGD} \end{aligned}$$

Similarly, 1 cubic foot per second equals  $60 \times 60 \times 24 = 86,400$  cubic feet per day; the number of gallons per day will be  $7.48 \times 86,400 = 646,300$ , or approximately  $2/3$  of a million gallons per day. Hence:

$$\begin{aligned} 1 \text{ c.f.s.} &= 2/3 \text{ MGD} \\ 1 \text{ MGD} &= 1.5 \text{ c.f.s.} \end{aligned}$$

*Example.* During 10 hours per day a station pumps with a 300 g.p.m. unit to a community with a population of 2,000. What is the plant output in million gallons per day, and what is the per capita consumption if the pump delivers as expected (frequently not the case)?

$$\begin{aligned} \text{Calculations.} \quad \text{Daily pumpage (gal.)} &= 60 \times 10 \times 300 \\ &= 180,000 \text{ gal.} \\ \text{Daily output (MGD)} &= \frac{180,000}{1,000,000} \\ &= 0.18 \text{ MGD} \\ \text{Per capita consumption (gal./capita/day)} &= \frac{180,000}{2,000} \\ &= 90 \text{ gal./capita/day} \end{aligned}$$

**Rate of Filtration.** Rate of filtration is expressed in terms of gallons per square foot per minute. Up until recently, 2 gal. /sq. ft./min. was considered as the standard rapid filter rate, but with good flocculation or with coagulant aids, this value may easily be exceeded. The term *times rate* refers to a rate of filtration or backwash compared with the normal filter rate. Inches of vertical rise (or fall) per minute measures filter or backwash rate in terms of the vertical movement of a water particle during a time interval of one minute. In older textbooks, rate of filtration was expressed in million gallons per acre per day (MGAD); the accepted standard rate was 125 MGAD, the equivalent of 2 gal./ sq. ft./min.

*Example.* How many inches drop per minute corresponds to the usual filter rate of 2 gal./sq. ft./min.?

$$\begin{aligned} \text{Calculations.} \quad \text{Quantity (cu. ft./min.)} &= \frac{2}{7.5} \\ &= 0.267 \text{ cu. ft./min.} \end{aligned}$$

Find the height of a prism of this volume whose base is 1 sq. ft.

$$\begin{aligned}\text{Height} &= \frac{0.267 \text{ cu. ft.}}{1 \text{ sq. ft.}} \\ &= 0.267 \text{ ft.} \\ \text{Drop (in.)} &= 12 \times 0.267 \text{ ft.} \\ &= 3.2 \text{ in.}\end{aligned}$$

The relation between filter rates may be stated as:

$$2 \text{ gal./sq. ft./min.} = 3.2 \text{ in./min.} = 1.0 \text{ normal rate} = 125 \text{ MGAD}$$

*Example.* A rapid sand filter whose surface measures 10 ft. by 15 ft. delivers an average of 500,000 gallons daily. What is the filter rating in gal./sq. ft./min.? How many gallons per minute of backwash water must be supplied to produce a vertical rise of 25 inches per minute?

$$\begin{aligned}\text{Calculations. Area of filter (sq. ft.)} &= 10 \text{ ft.} \times 15 \text{ ft.} \\ &= 150 \text{ sq. ft.}\end{aligned}$$

$$\begin{aligned}\text{Rating (gal./sq. ft./min.)} &= \frac{500,000}{150 \times 24 \times 60} \\ &= 2.32 \text{ gal./sq. ft./min.}\end{aligned}$$

$$\begin{aligned}\text{Required backwash rate (g.p.m.)} &= \frac{25}{3.2} \times 2 \times 150 \\ &= 2,340 \text{ g.p.m.}\end{aligned}$$

## CONVERSIONS

**Units of Concentration.** Perhaps the most frequent routine calculation entailed in calculating dosages and in reporting operating results is the conversion of values between the several concentration units, namely, pounds per million gallons (lb./MG), parts per million (p.p.m.), and grains per gallon (g.p.g.). The term grains per gallon involves the use of a unit of weight, the grain, that is awkward and relatively unfamiliar; very few operators can visualize its magnitude. However, this unit has long been used for the measurement of dosage. Aside from being established by custom, its only other justification for retention is that the volume mentioned is the common gallon. Pounds per million gallons is the logical dosage unit for the water plant because the pound is the unit of weight involved in the purchase and handling of materials,

and the million gallon unit is commonly used in connection with the daily output of a water plant. Parts per million, which is simply pounds per million pounds, is essentially a ratio similar to the term percentage, but with the base 1,000,000 rather than 100 as in the customary system. This large base is selected so that the relatively small quantities involved in water composition and treatment are represented by conveniently sized numbers. Thus  $100/1,000,000 = 0.0001$ , or 1 p.p.m. = 0.001%, which relations indicate that the percentage system yields too unwieldy a decimal value for easy use in water treatment.

Since 1,000,000 gallons weigh  $8.34 \times 1,000,000$  pounds

8.34 pounds per million gallons (lb./MG) = 1 part per million (p.p.m.)

The equivalent of 1 grain per gallon is obtained from the following relations:

$$\begin{aligned} 1 \text{ pound} &= 7000 \text{ grains} \\ \text{or, } 1 \text{ grain} &= 1/7000 \text{ pound} \\ 1 \text{ gallon} &= 8.34 \text{ pounds} \end{aligned}$$

$$\begin{aligned} \text{then, } 1 \text{ grain per gallon} &= \frac{1/7000 \text{ lb.}}{8.34 \text{ lb.}} = \frac{1}{58,380}, \\ &\text{or } 1 \text{ lb. in } 58,380 \text{ lb.} \end{aligned}$$

$$\text{Since } \frac{1,000,000}{58,380} = 17.12$$

$$1 \text{ grain per gallon (g.p.g.)} = 17.12 \text{ parts per million (p.p.m.)}$$

Likewise,

$$\begin{aligned} 1 \text{ grain per gallon (g.p.g.)} &= 8.3 \times 17.12 \\ &= 142.8 \text{ pounds per million gal-} \\ &\quad \text{lons (lb./MG)} \end{aligned}$$

*Example.* In treating 800,000 gallons of water, 150 pounds of a certain chemical was used. What was the dosage expressed in pounds per million gallons and in parts per million?

$$\begin{aligned} \text{Calculations. } \text{Dosage (lb./MG)} &= 150 \times \frac{1,000,000}{800,000} \\ &= 188 \text{ lb./MG} \\ \text{Dosage (p.p.m.)} &= \frac{188}{8.3} \\ &= 22.6 \text{ p.p.m.} \end{aligned}$$

#### EXAMPLE

*Pipe-line Disinfection.* A newly laid 12-inch pipe-line 1400 feet long is to be disinfected by soaking overnight with heavily

chlorinated water, intended orthotolidine residual 50 p.p.m., prepared from HTH, 70% available chlorine, and introduced through a corporation cock at the end tied in with the existing feeder. How much HTH will be needed?

*Calculations*

$$\begin{aligned}
 \text{Intended residual} &= 50 \text{ p.p.m.} \\
 \text{Chlorine dosage allowing} & \\
 \text{for about 10\% chlorine} & \\
 \text{demand} &= 50/0.9 \\
 &= 55.6 \text{ p.p.m.} \\
 \text{HTH dosage, allowing for} & \\
 \text{70\% strength} &= 55.6/0.70 \\
 &= 79.4 \text{ p.p.m.} \\
 (\text{lb./MG}) &= 8.3 \times 79.4 \\
 &= 659 \text{ lb./MG} \\
 \text{Volume of pipe-line (gal.)} &= 0.785 \times \left(\frac{12}{12}\right)^2 \times 1400 \times 7.5 \\
 &= 8,240 \text{ gal.} \\
 \text{HTH needed (lb.)} &= 658 \times 8,240/1,000,000 \\
 &= 5.42 \text{ lb.} \\
 &= 0.42 \times 16 \text{ ounces} = 6.7 \text{ oz.} \\
 &= 5 \text{ lb. } 7 \text{ oz.}
 \end{aligned}$$

For details of injection see Chapter 9.

**Dry Feeder Rate.** The rate of dry feeder discharge of chemicals must be changed with change in pumpage, in cases where the flow may vary by a number of separate steps, and also with changes in the character of the water. As the feeder dial is divided into arbitrary units, a check on the rate of feed is advisable each time a change is made in the setting, or when there is a change in the flow characteristics of the powdered chemical from different batches. A check-up is desirable in many plants as a matter of routine control and record.

In order to check the feed, the pumping rate must be known, either in terms of gallons per minute or million gallons per day. A pot is placed to catch the powder discharged for a certain interval of time, generally one minute, and this material is weighed, in grams or in ounces. This weight is compared with the desired amount and suitable readjustment of the setting made.

*Example.* In a plant operating at the rate of 500,000 gallons per day, how many grams per minute must the dry feed machine discharge in order to apply a dosage of 15 parts per million?

$$\begin{aligned}
 \text{Calculations.} \quad \text{Dosage (lb./MG)} &= 8.3 \times 15 \\
 &= 124.5 \text{ lb./MG} \\
 \text{Pounds per day} &= 124.5 \times 0.5 \\
 &= 62.3 \text{ lb./day} \\
 \text{Since 1 lb.} &= 453.6 \text{ grams} \\
 \text{Feed rate (grams per minute)} &= \frac{62.3 \times 453.6}{60 \times 24} \\
 &= 19.6 \text{ g./min.}
 \end{aligned}$$

**Special Catchment Period for Checking Dry Feed.** For plants where the pumpage rate is constant or restricted to a few steps, the chemical consumption in pounds per 24 hours or the dosage, say in pounds per million gallons, may be obtained directly from the weight on a scale, thus eliminating all calculation, if the discharge is caught for certain time intervals. The principles underlying this method are best illustrated by a specific example.

*Example.* In a plant whose pumping rate is set at 1.4 million gallons per day calculate the dry feed catchment time so that the weight of discharged chemical in grams equals (a) pounds per 24 hours, and (b) pounds per million gallons.

*Calculations*

$$\begin{aligned}
 \text{(a) Rate of feed (lb./24 hr.)} &= \text{lb./sec.} \times \text{sec./24 hr.} \\
 &= \frac{\text{g./sec.}}{453.6} \times 86,400 \\
 &= 191 \times \text{g./sec.} \\
 &= \text{grams per 191 seconds} \\
 &\quad \text{(3 min., 11 sec.)} \\
 \text{(b) Dosage (lb./MG)} &= \frac{\text{lb./24 hr.}}{\text{MGD}} \\
 &= \frac{\text{g./191 sec.}}{\text{MGD}} \\
 &= \text{g./} \frac{191}{1.4} \text{ sec.} \\
 &= \text{grams per 136 seconds} \\
 &\quad \text{(2 min., 16 sec.)}
 \end{aligned}$$

Thus the weight in grams collected during 191 seconds numerically equals the chemical consumption in pounds per 24 operating hours; while the weight caught in 136 seconds shows directly the dosage in pounds per million gallons. The first figure is a constant, but the second must be revised whenever the pumpage rate is changed.

**Dry Feed Chart.** The accompanying chart, Figure 44, permits checking off a dry feeder without direct calculation by the

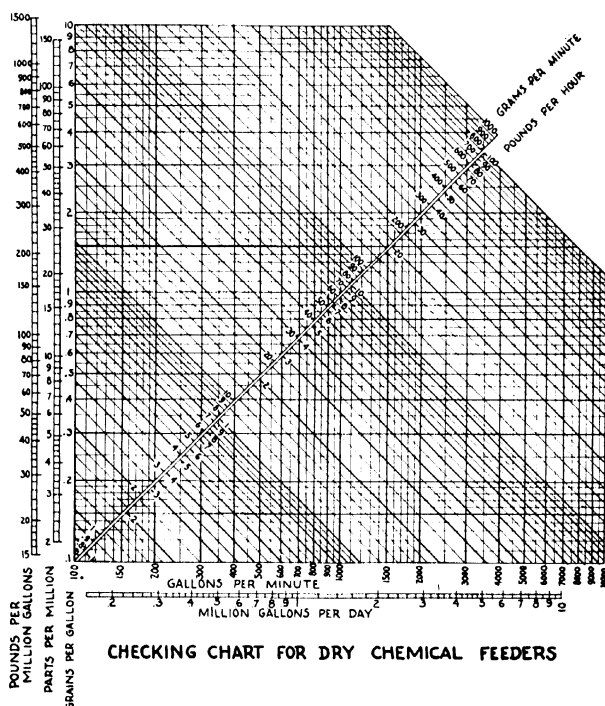


FIGURE 44

Checking Chart for Dry Chemical Feeders

(Courtesy of *Water Works & Sewerage*)

operator. To solve the preceding problem by means of the chart, locate 15 on the parts per million scale and carry this point horizontally until directly over the 0.5 million gallon per day position found on the bottom scale. Follow this point of intersection diagonally downward along the slope as shown to the divided central scale where the reading, 19.8 g./min., is taken. Reading across the gap at the central scale, it will be seen that 2.65 pounds per hour of material will be used and the operator can judge from this how long a hopper charge will last.

If the point of intersection falls in the area occupied by the pounds per hour diagonals, readings are converted in like manner to grams per minute by projecting directly across the sloping division. When a metric scale is unavailable, grams per minute may be obtained directly by catching the dry feeder discharge for 170 seconds and multiplying the weight in ounces by 10.

**Pressure Conversions.** Pressures are expressed in terms of feet of water (ft. water) standing above the reference point, in pounds per square inch (psi.) and in inches of mercury (in. Hg.). Feet of water represents the height a water column would rise in an open vertical tube if connected to the pressure point; this unit is important in many hydraulic formulas. Its measurement may also be made directly with a so-called altitude gage whose dial is marked off to read in feet of water. If a liquid manometer, or pressure tube, is used with high pressures, as on a pump discharge, a water column would stand at an excessive height. By using a much heavier liquid, namely mercury, the tube may be shortened so compactly that readings can be taken in inches. Pounds per square inch measures the pressure exerted uniformly at the point of measurement over each square inch of surface; this reading is taken from a gage similar in construction to an altitude gage but with the dial marked off in pounds per square inch. A combination gage is frequently used in which the index points over a double ruled



scale, one in feet of water and the other in pounds per square inch.

The relations between these units of pressure may be shown readily. A rectangular column of water 1 foot high and 1 square inch in cross section will bear on its base with its own weight of  $8.34 \times 12/231 = 0.433$  pounds. (1 gallon = 231 cubic inches and weighs 8.34 pounds.) Therefore,

$$\begin{array}{l} 1 \text{ ft. water} = 0.433 \text{ psi.} \\ \text{or,} \quad 1 \text{ psi.} = 2.31 \text{ ft. water} \end{array}$$

Since an equal volume of mercury weighs 13.6 times as much as water, 1 foot of water is equivalent to  $1/13.6$  feet of mercury or  $(12 \times 1/13.6) = 0.883$  inches of mercury. This relation applies to an open-end manometer as ordinarily used. However, if both arms of a mercury U-tube are connected to water pressure, as in a differential manometer, an allowance must be made for the density of water in the depressed section of the high pressure arm. In effect, the density of mercury is reduced to 12.6 and 1 foot of water becomes equivalent to  $1/12.6$  feet of mercury or  $(12 \times 1/12.6) = 0.953$  inches of mercury. Thus:

$$\begin{array}{l} 1 \text{ ft. water} = 0.883 \text{ in. Hg. (Open tube manometer with water} \\ \quad \quad \quad \text{in one arm only.)} \\ 1 \text{ ft. water} = 0.953 \text{ in. Hg. (Differential manometer, with both} \\ \quad \quad \quad \text{arms subject to water pressure.)} \end{array}$$

*Example.* The water level in a close-by elevated tank is 140 feet above the pumping station instrument board. What does the pressure gage read?

$$\begin{array}{l} \text{Calculation.} \quad \text{Pressure (psi.)} = 0.433 \times 140 \\ \quad \quad \quad \quad \quad \quad \quad = 60.7 \text{ psi.} \end{array}$$

## ENERGY AND EFFICIENCY

Power cost is a major item of expense in furnishing a water supply, therefore, the monthly bill for electric current should be examined for any changes in the cost to pump some convenient quantity, for example, 1,000 gallons. If this unit cost

risks consistently, a decrease in pump efficiency may be indicated, and proper repairs should follow.

By power is meant the rate of doing work in a given time. Work is measured by the foot-pound, which unit represents the work performed when lifting a pound weight a vertical distance of one foot. Since water weighs 8.34 pounds per gallon, a foot-pound of work is expended in lifting 1 gallon of water through a height of  $1/8.34 = 0.1199$  feet = 1.44 inches. A horsepower is defined as the rate of work performing 33,000 foot-pounds per minute, or 550 foot-pounds per second. This quantity of work is equivalent to pumping 33,000 gallons through a height of 0.1199 feet, or 1 gallon through  $33,000 \times 0.1199 = 3,965$  feet; or, in general, pumping 3,965 gallon-feet per minute is a pump horsepower. From the relation  $0.746$  kilowatts (kw.) = 1 horsepower, the water pumpage theoretically equivalent to 1 kilowatt is  $3,965/0.746 = 5,319$  gallon-feet per minute. Because of the loss of energy through friction, stray currents and hydraulic effects, pumping in practice requires an appreciably greater input of energy than can be recovered as effective work. The ability of a machine to transform energy into actual work is measured by a ratio known as the efficiency.

$$\begin{aligned}\% \text{ Efficiency} &= \frac{\text{Work output}}{\text{Energy input}} \times 100 \\ &= \frac{\text{kw. recovered in pumpage}}{\text{kw. input as metered}} \times 100\end{aligned}$$

The usual over-all efficiency, or "wire-to-water efficiency," in a motor driven pump set is usually in the neighborhood of 65%. If the efficiency is much lower and the unit is much used, its repair or replacement will prove economical. Knowing the kilowatt consumption, the current in amperes may be figured from the relation:

$$\begin{aligned}\text{For direct current, amperes (amp.)} &= \frac{\text{kilowatts} \times 1000}{\text{volts}} \\ \text{For each leg of a 3 phase current, amperes (amp.)} &= \frac{\text{kilowatts} \times 100}{\text{volts} \times 1.73 \times \text{power factor}}\end{aligned}$$

*Example.* During the 10 hours it operates each day, a station pumps 600,000 gallons from a water level in the well 40 feet below the ground surface and maintains an average of 80 pounds per square inch pressure at the pump discharge. If the meter readings show 15,500 kilowatt hours are used, what is the kilowatt hour consumption per 1,000 gallons, and what is the wire-to-water efficiency? If charged 2 cents per kilowatt hour for power, what is the cost in cents per 1,000 gallons pumped and how much is the monthly electric bill?

*Calculations.* Discharge pressure (ft. water) =  $2.31 \times 80$  psi.  
= 184.8 ft. water

Total lift (ft. water) = 184.8 (discharge) + 40 (suction)  
= 224.8 ft. water

Power (kw.) =  $\frac{600,000 \times 224.8}{60 \times 10} \times \frac{1}{5,319}$   
= 42.3 kw.

Energy utilized monthly (kw. hr.) =  $42.3 \times 10 \times 30$   
= 12,690 kw. hr.

Energy metered per month (kw. hr.) = 15,500 kw. hr.

Efficiency (%) =  $\frac{12,690}{15,500} \times 100$   
= 81.6%

Kw. hr. per 1000 gal. =  $\frac{15,500}{30 \times \frac{600,000}{1,000}}$   
= 0.86

Monthly electric bill =  $\$0.02 \times 15,500$   
= \$310.00

Pumping cost per 1000 gal. =  $\frac{\$310.00}{\frac{600,000}{1,000} \times 30}$   
= 1.72¢

A simple method for measuring the electrical energy consumed during a short period is by counting the revolutions of the aluminum disc, or armature, in the electric meter. Each turn represents the number of watt-hours shown by the meter constant,  $k_h$ . Thus if  $k_h = 13$ , the power consumption of a connected load is given by the formula: watts = r.p.m. of disc  $\times 60 \times 13$ .

## AIDS TO CALCULATION

Devices useful in performing calculations and figuring reports include the calculating machine, slide rule, graphs and charts. The calculating machine is advantageous for preparing reports, but the cost is above the reach of all but larger plants. The slide rule is possibly the most handy calculating aid available to the operator. Prices range from 15 cents for an economical but serviceable rule to \$15 for the best in imitation ivory scale varieties. Every plant operator should own some sort of slide rule and master the simple applications to multiplication, division and extraction of roots. Manuals of instruction usually accompany the sale of an instrument.

Operators should also collect graphs, nomograms and other charts of possible value, that occasionally appear in the trade journals. These drawings are usually accompanied with directions for their use. In this manual, such calculation charts designed to aid the plant operator in frequently recurring problems are found in Figures 26, 28, 33, 37, 39, 44, 46, 49 and 50.

## CHAPTER 19

### CHEMICAL TESTS

IN THIS chapter are presented some chemical determinations that are useful in the operation of a water plant. Methods have been selected that are simple, rapid and reliable, in order to be within the reach of a water plant with only a minimum of laboratory equipment. These tests should supplement or accompany direct observations of the condition of the water in basins, reservoirs and filters. More scientifically correct procedures are published in the *Standard Methods for Water Analysis* but many of these are too rigid for the operator who has had no previous chemical training. Hence, the simplified directions and explanations that follow.

**General Precautions.** Water samples should be representative of the whole volume passing the sampling point at the time of collection. When collecting turbid samples, the bottle should be exposed and filled throughout as sufficient a cross-section of the stream or basin as previous experience shows to be necessary. In sampling well water for gases, the sample should be taken directly at the well and not at the delivery end of the pipe to the plant. Some tests, for example, those for carbon dioxide, dissolved oxygen, dissolved iron, pH, residual chlorine and phenolphthalein alkalinity, should be run immediately after collection of samples.

Only when turbidity in a sample interferes with accurate determinations should the water be cleared. Filtration through filter paper is a usual method, discarding the first runnings, but this method may lead in some tests to large errors. The Berkefeld filter candle, which is a porous cylinder of diatomaceous earth mounted in a special tubular container and

operated by suction, is probably the best filter medium for removal of turbidity, as for color tests. In tests for pH and phenolphthalein alkalinity, filtration alters the results, hence the sample should be cleared in a centrifuge when the original water is too turbid for testing.

Clean laboratory ware is essential if trustworthy results are to be expected. After a piece of equipment is used, it should be rinsed immediately and placed in a closed cabinet. This is particularly important in lime softening plants where lime dust may float in the air.

Weighing out of chemicals for the preparation of precise standard solutions for titrations or color matching should be made on a regular analytical balance, or, where none is available, a druggist's prescription scale will suffice. An ordinary laboratory platform balance, if in good condition, may be used for preparing indicators and reagent solutions that require more than 5 to 10 grams of material.

Many of the tests are titrations in which a standard strength solution is added from a graduated tube, called a buret, to a measured amount of water sample. Where routine titrations are made, an automatic buret should be provided in order to facilitate the test and to protect the standard solution from deterioration. In reading a buret the eye should be at the same height as the level of the liquid. The reading is taken at the bottom of the concave shadow, or meniscus, in the tube.

**Formulas.** The results of all tests involving hardness and alkalinity are usually stated in terms of parts per million of calcium carbonate. This convention is widely adopted in water chemistry as calcium carbonate is a principal product in lime softening, it is a compound which causes both hardness and alkalinity, and finally, because it bears a very convenient numerical relation useful in conversion calculations.

An explanation of the various popularly used systems of expressing concentration is given in Chapter 18 in connection with plant arithmetic.

Formulas are listed in the following table for nearly all chemicals ordinarily used in water treatment. These formulas should be considered as a precise shorthand method for designating the composition of a definite material.

TABLE 14  
Chemical Formulas of Compounds Encountered  
in Water Chemistry

(A) DISSOLVED SALTS AND COMPOUNDS

|                       |                             |
|-----------------------|-----------------------------|
| Calcium bicarbonate   | $\text{Ca}(\text{HCO}_3)_2$ |
| Calcium carbonate     | $\text{CaCO}_3$             |
| Calcium sulfate       | $\text{CaSO}_4$             |
| Calcium chloride      | $\text{CaCl}_2$             |
| Calcium hydroxide     | $\text{Ca}(\text{OH})_2$    |
| Magnesium bicarbonate | $\text{Mg}(\text{HCO}_3)_2$ |
| Magnesium carbonate   | $\text{MgCO}_3$             |
| Magnesium sulfate     | $\text{MgSO}_4$             |
| Magnesium chloride    | $\text{MgCl}_2$             |
| Magnesium hydroxide   | $\text{Mg}(\text{OH})_2$    |
| Sodium bicarbonate    | $\text{NaHCO}_3$            |
| Sodium carbonate      | $\text{Na}_2\text{CO}_3$    |
| Sodium sulfate        | $\text{Na}_2\text{SO}_4$    |
| Sodium chloride       | $\text{NaCl}$               |
| Sodium hydroxide      | $\text{NaOH}$               |
| Silica                | $\text{SiO}_2$              |
| Alumina               | $\text{Al}_2\text{O}_3$     |
| Ferric oxide          | $\text{Fe}_2\text{O}_3$     |
| Ferrous bicarbonate   | $\text{Fe}(\text{HCO}_3)_2$ |
| Manganese bicarbonate | $\text{Mn}(\text{HCO}_3)_2$ |

(B) COMPOUNDS USED IN TREATMENT

| Common Name  | Chemical Name     | Formula                  |
|--|-------------------|--------------------------|
| <i>Softening</i>   |                   |                          |
| Unslaked lime }<br>Quicklime }<br>Slaked lime }<br>Hydrated lime } | Calcium oxide     | $\text{CaO}$             |
|  | Calcium hydroxide | $\text{Ca}(\text{OH})_2$ |
| Soda ash   | Sodium carbonate  | $\text{Na}_2\text{CO}_3$ |
| Caustic soda   | Sodium hydroxide  | $\text{NaOH}$            |
| Zeolite  | —                 | $\text{NaZ}$ (symbolic)  |
| Salt   | Sodium chloride   | $\text{NaCl}$            |

## (B) COMPOUNDS USED IN TREATMENT (Continued)

| Common Name          | Chemical Name                                       | Formula  |
|----------------------|---|--|
| <i>Coagulation</i>   |   |  |
| Alum                 | Aluminum sulfate                                    | $\text{Al}_2(\text{SO}_4)_3 \cdot 17-18 \text{ H}_2\text{O}$                               |
| Copperas             | Ferrous sulfate                                     | $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$  |
| Green vitriol        |   |  |
| Chlorinated copperas | Equal mixture of ferric sulfate and ferric chloride | $\left\{ \begin{array}{l} \text{Fe}_2(\text{SO}_4)_3 \\ \text{FeCl}_3 \end{array} \right.$ |
| Ferric sulfate       | Ferric sulfate                                      | $\text{Fe}_2(\text{SO}_4)_3$   |
| Ferric chloride      | Ferric chloride                                     | $\text{FeCl}_3$  |
| Sodium aluminate     | Sodium aluminate                                    | $\text{Na}_2\text{Al}_2\text{O}_4$   |
| Water glass          | Sodium silicate                                     | $\text{Na}_2\text{Si}_2\text{O}_6$   |
| <i>Disinfection</i>  |   |  |
| Chlorine             | Chlorine  | $\text{Cl}_2$  |
| Ammonia              | Ammonia   | $\text{NH}_3$  |
| Ammonia water        | Ammonium hydroxide                                  | $\text{NH}_4\text{OH}$   |
| Ammonium sulfate     | Ammonium sulfate                                    | $(\text{NH}_4)_2\text{SO}_4$   |
| Chloramines          | Monochloramine                                      | $\text{NH}_2\text{Cl}$   |
|                      | Dichloramine  | $\text{NHCl}_2$  |
| Ozone                | Ozone   | $\text{O}_3$   |
| <i>Miscellaneous</i> |   |  |
| Iron                 | Iron  | $\text{Fe}$  |
| Copper               | Copper  | $\text{Cu}$  |
| Bluestone            | Copper sulfate                                      | $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$  |
| Oxygen               | Oxygen  | $\text{O}_2$   |
| Carbon dioxide       | Carbon dioxide                                      | $\text{CO}_2$  |
| Hydrogen sulfide     | Hydrogen sulfide                                    | $\text{H}_2\text{S}$   |
| Natural gas          | Methane (impure)                                    | $\text{CH}_4$  |
| Fluorine             | Fluorine  | $\text{F}$   |
| Activated carbon     | Carbon  | $\text{C}$   |
| Calgon               | Sodium hexametaphosphate                            | $(\text{NaPO}_3)_6$  |

## METHODS

## FREE CHLORINE—

## PARA-AMINODIMETHYLANILINE METHOD

**Principle.** In a solution buffered between pH 6.0 to 7.0, para-aminodimethylaniline in the presence of free chlorine, as distinguished from chloramines or other combined forms, produces a red flash color which is compared with standards. Below pH 6.0 chloramines cause false color; ferric iron (0.1



p.p.m.) and manganic compounds interfere. This method is semi-quantitative.

### **Solutions**

1. Basic fuchsin stock solution (50 mg./l.).

From this is prepared the more dilute solution whenever needed.

2. Dilute basic fuchsin solution.

Dilute 25 ml. basic fuchsin stock solution to 500 ml. with distilled water.

3. Copper acetate standard solution, 0.1 M.

Dissolve 19.96 g. copper acetate,  $\text{Cu}(\text{C}_2\text{H}_3\text{O}_2) \cdot \text{H}_2\text{O}$ , in 1 liter of distilled water.

The above solutions are used for preparation of standards.

4. Saturated solution of para-aminodimethylaniline hydrochloride in acetone as indicator.

This solution is unstable toward light and must be kept in a brown bottle; it may be used for several weeks.

5. Buffer solution, pH 6.4.

Dissolve 1.3616 g. of acid potassium phosphate,  $\text{KH}_2\text{PO}_4$ , and 0.101 g. of sodium hydroxide, each in a small amount of distilled water. Mix and dilute to 200 ml. As this buffer solution requires care in its preparation, most plants will profit by ordering it directly from a chemical supply house.

6. Phosphoric acid, 10%.

### **Preparation of Standards**

| Chlorine<br>p.p.m. | Dilute Basic Fuchsin<br>Solution<br>ml. | Copper Acetate<br>Solution<br>ml. |
|--------------------|---|-----------------------------------|
| 0.05               | 2.2                                     | 0.7                               |
| 0.10               | 3.5                                     | 1.0                               |
| 0.20               | 7.0                                     | 1.8                               |
| 0.30               | 13.5                                    | 2.6                               |
| 0.40               | 17.0                                    | 2.6                               |

Add the amounts of basic fuchsin and copper acetate solutions, as tabulated above, to a 50 ml. Nessler tube and dilute to the mark with distilled water. These standards show no fading within five weeks' use.

**Procedure.** Pour 50 ml. of water sample into a Nessler tube, add 2 ml. of buffer solution, then 0.5 ml. of indicator solution. Compare the red color with the standards.

Samples containing more than 0.40 p.p.m. free chlorine should be diluted with chlorine free, zero demand water (distilled water which has been lightly chlorinated and excess boiled off) in order to obtain a color match. If the pH of the sample lies between 6.0 to 7.5, the buffer solution may be omitted. Development of color at low temperatures is slow; the test may be hastened by immersing the Nessler tube containing the sample in a water bath held near 100°F.

If no color is obtained, test for chloramines by adding 3 or 4 drops of 10% phosphoric acid to reduce the pH below 4.0 where chlorine is released from chloramines. A red color, slower to form than with free chlorine already present, indicates the presence of chloramines.

### RESIDUAL CHLORINE—ORTHOTOLIDIN METHOD

**Principle.** Orthotolidin reacts with small amounts of both free chlorine and chloramines to form a greenish color if the water sample is acidified to a pH not above 2.0. If the pH is much higher than 1.3, the color formation becomes erratic. The color is matched against standards prepared in the laboratory in Nessler tubes or similar containers, or duplicated in colored glass discs mounted in a comparator. For most purposes, the use of a comparator is preferred for convenience. The presence of any other oxidizing agent will give a false test; such interference is caused by a concentration of ferric iron above 0.3 p.p.m., nitrites exceeding 0.1 p.p.m. as nitrogen, and hydrated manganic oxides in excess of 0.01 p.p.m. as manganese.

#### Solutions

1. Copper sulfate solution.

Dissolve 1.5 g. of copper sulfate,  $\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$ , in a small

amount of distilled water, add 1 ml. of concentrated sulfuric acid and dilute to 100 ml.

2. Potassium dichromate solution.

Dissolve 0.025 g. of potassium dichromate in a small amount of distilled water, add 0.1 ml. of concentrated sulfuric acid, then dilute to 100 ml.

The above solutions are used for preparation of standards.

3. Orthotolidin solution as indicator.

Dissolve 1.35 g. of orthotolidin dihydrochloride in 850 ml. of distilled water, then add with constant stirring 150 ml. of concentrated hydrochloric acid.

When the readily soluble orthotolidin dihydrochloride is not obtainable, the indicator solution is prepared directly from orthotolidin as follows: Grind 1.0 g. of orthotolidin in a mortar with 5 ml. of dilute hydrochloric acid (1.5 ml. of acid: 3.5 ml. of distilled water) to form a thin paste. Pour off into a liter flask containing 200 ml. distilled water to dissolve the acidified orthotolidin. Add 150 ml. of concentrated hydrochloric acid, shake, and dilute to a liter with distilled water. Preserve in a dark bottle; prepare a fresh portion every six months.

**Preparation of Standards**

| Residual<br>Chlorine<br>p.p.m. | Potassium Dichromate<br>Solution<br>ml. | Copper Sulfate<br>Solution<br>ml. |
|--------------------------------|---|-----------------------------------|
| 0.05                           | 5.5                                     | 0.4                               |
| 0.10                           | 10.0                                    | 1.8                               |
| 0.15                           | 15.0                                    | 1.8                               |
| 0.20                           | 20.0                                    | 1.9                               |
| 0.30                           | 30.0                                    | 1.9                               |
| 0.40                           | 38.0                                    | 2.0                               |
| 0.50                           | 45.0                                    | 2.0                               |
| 0.60                           | 51.0                                    | 2.0                               |
| 0.80                           | 63.0                                    | 2.0                               |
| 1.00                           | 72.0                                    | 2.0                               |

Combine the potassium dichromate and copper sulfate solutions according to the schedule above and dilute the mixture to 100 ml. with distilled water. These standards should best be placed in 100 ml. Nessler tubes for matching but ordinarily

no appreciable loss in accuracy is incurred if the standards are contained in 8-ounce glass stoppered sample bottles, or similar bottles like that in which the test sample is drawn. Keep the standards in a lightproof box when not actually in use. They should be renewed every six or eight months.

Above 1.00 p.p.m. residual chlorine, the color gradations become harder to distinguish. At still higher chlorine concentrations, the character of the color changes entirely to a terracotta type which precipitates on standing.

**Procedure.** Draw about 100 ml. of water sample in a bottle similar to those containing the standards. Add 5 ml. of orthotolidin solution. After several minutes, when the maximum color development will have been reached, compare with the color standards. At temperatures below 60°F. the color development becomes sluggish and the sample should be warmed in a water bath to about 80° while testing.

Waters of high alkalinity give irregular colors by reducing the acidity of the indicator. Where this interference is evident, a double quantity of indicator should be used to keep the pH of the test mixture below the prescribed limit. False color caused by nitrites does not ordinarily confuse a test because the color, which develops so slowly, is straw-yellow rather than the typical greenish-yellow of residual chlorine. Nitrites will not interfere if the color is allowed to develop in a dark cabinet. A maximum estimate of the effect of manganese may be calculated by multiplying the total manganese, in p.p.m., by 0.65; this gives the greatest possible value of the false residual in p.p.m. due to this factor. False residuals in a water sample may be estimated by boiling off 25% of the sample to expel the chlorine before running the residual test. If chloramines are absent, the original sample may be allowed to stand till the next day before testing for a false residual. By means of sodium arsenite solution in conjunction with orthotolidin, as described later, errors caused by false colors can be effectively avoided.

When chlorine has been applied to exceed the break-point, almost the full residual color flares up instantly after adding the indicator; this constitutes the so-called flash test.

In using a comparator, the directions furnished with the instrument should be followed. A popular type of comparator with glass disc color standards takes a 15 ml. sample volume with 0.75 ml. (1 dropperful) of orthotolidin reagent. Any other sample volume will require a reagent volume in proportion.

### HEAVY CHLORINE RESIDUALS— ORTHOTOLIDIN DROP DILUTION METHOD

**Principle.** Heavily chlorinated waters which ordinarily cause an orange-red color or precipitate with orthotolidin may be tested if sufficiently diluted with chlorine-free zero-demand water before adding the indicator.

#### **Solutions**

1-3. As in ordinary orthotolidin test.

4. Chlorine free, zero-demand water.

Add a drop of concentrated sulfuric acid to 1 liter of distilled water and boil off about 100 ml. to expel ammonia. Cool. Add enough chlorine water to cause a 0.5 p.p.m. residual. Let stand half an hour, boil again to expel chlorine, and cool to room temperature. Prepare fresh daily as needed.

**Procedure.** Add 1 ml. of heavily chlorinated water to 99 ml. of chlorine-free, zero-demand water in a sample bottle or Nessler tube. Introduce 1 ml. of orthotolidin solution. Match the color with the standards as in the usual orthotolidin test. Multiply the reading by 100. This particular dilution is useful in testing residuals when sterilizing new pipe lines. Other dilutions are used when required.

When performed in a comparator, a single drop or two of the heavily chlorinated water is used as the sample and diluted to the mark on the cell with chlorine-free, zero-demand water.

The residual test is then run and the reading multiplied by a dilution factor best found by trial.

### FALSE RESIDUALS—SODIUM ARSENITE METHOD (OTA TEST)

**Principle.** The interfering coloration of orthotolidin caused by the presence of manganese, ferric iron and nitrites will persist in the presence of sodium arsenite solution, but the color due to chlorine will be repressed. Therefore, a residual determined with sodium arsenite present represents the interferences, and the difference between the usual orthotolidin residual and the interferences measures the true residual due to chlorine or chloramines. Free chlorine and total chlorine with chloramines is distinguished by determining the corrections for interferences to be applied to the immediate and the 5-minute residuals, respectively. The flash coloration from free chlorine forms at water temperatures as low as 40°F., but full development of chloramine color requires preliminary warming of cold waters to 70°F. Temperatures above 80°F. should be avoided, as the speedy chloramine coloration may interfere with flash test readings.

#### Solutions

1. Orthotolidin solution.

As in the ordinary test.

2. Sodium arsenite solution.

Dissolve 10 g. of sodium arsenite in 1 liter of distilled water. For best keeping qualities, this solution should be made slightly acid to methyl orange indicator by means of 1:10 hydrochloric acid.

**Procedure.** To 15 ml. of water sample add 0.38 ml. (approximately half a dropperful) of sodium arsenite solution; mix thoroughly, then add 0.75 ml. (approximately a dropperful) of orthotolidin solution. If some other sample volume is used, the amounts of reagents should be proportioned accordingly. Read

the immediate and the 5-minute residuals due to interferences. Repeat the residual test with 0.75 ml. of orthotolidin solution only and again record the immediate and the 5-minute residuals. Keep exposure to light at a minimum.

|                                       |   |                                      |   |  |
|---------------------------------------|---|--------------------------------------|---|--|
| True chlorine, p.p.m.                 | = | Immediate residual with orthotolidin | — | Immediate residual with sodium arsenite and orthotolidin |
| True chlorine and chloramines, p.p.m. | = | 5-minute residual with orthotolidin  | — | 5-minute residual with sodium arsenite and orthotolidin  |

Using the popular types of comparators, which employ either colored glass discs or solution standards, the OTA test may be made to read directly the chlorine and the chlorine plus chloro-compounds by setting up test mixtures as in the illus-

| Reading time | Color representations                         |                     | Interpretation of disc reading |
|--------------|---|---------------------|--------------------------------|
| Immediate    | Free chlorine<br>Rapid Interferences          | Rapid Interferences | Free chlorine                  |
| 5 minutes    | Free chlorine<br>Chloramines<br>Interferences | Interferences       | Free chlorine and chloramines  |

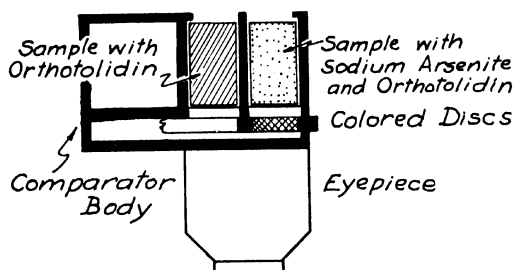


FIGURE 45

Arrangement of Test Cells in Colored Disc Comparator for Direct Readings with Sodium Arsenite-Orthotolidin Test for True Chlorine and Chlorine Compounds Residuals

tration, Figure 45. In place of the usual blank, a cell is substituted containing the OTA test mixture which furnishes the interference corrections instrumentally. For the sake of speed in performance, the orthotolidin solution is added to the arsenited sample before injecting into the regular orthotolidin test cell. The colored discs then measure only the difference between the two cells, and if read immediately and again after five minutes, give the true free chlorine and the total chlorine, active and loosely bound, respectively. A similar scheme may be used with solution standard comparators by replacing the blank cells for original sample with the OTA mixture.

## CHLORINE DEMAND AND BREAK-POINT

**Principle.** The chlorine demand of a water may be arbitrarily defined as the dosage required to produce a 0.1 p.p.m. residual with the orthotolidin test or by starch-iodide titration after a 10-minute contact period. This value measures the lower limit of chlorine dosage for so-called marginal chlorination. Since the orthotolidin method for measuring the residual does not distinguish between free chlorine and chlorine loosely combined with free or added ammonia and organic compounds, the chlorine residual so indicated may all be combined. Combined chlorine is not nearly so bactericidal as free chlorine. By increasing the chlorine dosage, the residual will also increase at first as expected, but in waters containing ammonia and organic nitrogen compounds, this increase in residual becomes progressively smaller; the residual will frequently decrease, even to zero. In typical cases, further addition of chlorine will then build up a residual proportional to the dosage. These relations have been already shown on the break-point chlorination curve in Figure 27.

The point at which the residual dips to a minimum is termed the break-point because a plot between residual and dosage shows a sharp break at this particular chlorine dosage, and the



characteristics of the water are changed markedly. Slightly beyond the break-point, free chlorine exists uncombined and gives characteristic tests such as the flash orthotolidin coloration, bleaching of methyl orange, and similar effects described in Chapter 9.

In performing a break-point test, a set of samples is dosed with increasing quantities of chlorine and allowed some period for reaction similar to plant retention. Then the residuals are determined and results plotted. At the same time, the variously dosed samples should be judged for taste, odor removal, color, and in some cases for coagulation characteristics and bacteria.

### **Solutions**

#### **1. Sodium thiosulfate solutions.**

Dissolve 6.205 g. of sodium thiosulfate,  $\text{Na}_2\text{S}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$ , in freshly boiled distilled water and make up to 1 liter. Add 5 ml. of chloroform as a preservative. This N/40 solution is used for standardizing the chlorine water; it loses strength after a few weeks standing. Dilute 10 ml. of this stock solution to 88.6 ml. for titration of residual chlorine; then 1 ml. is equivalent to 0.1 mg. of chlorine. The dilute solution is unreliable if over a day old.

#### **2. Potassium iodide solution.**

Dissolve 100 g. of potassium iodide in distilled water and dilute to 1 liter.

#### **3. Starch indicator solution.**

Grind about 5 g. of potato starch in a mortar with a small volume of water. Pour rapidly into about a liter of boiling water while stirring. Settle overnight and draw off the clear solution. Add 1.25 mg. of salicylic acid per liter as a preservative.

#### **4. Chlorine water.**

Bubble chlorine gas through distilled water in a glass-stoppered bottle until saturated. Dilute 100 ml. to 1 liter with distilled water as needed.

*Standardization.* Into a 250-ml. Ehrlenmeyer flask, contain-

ing 100 ml. of distilled water and 2 ml. of potassium iodide solution, pipette 10 ml. of chlorine water and stand 5 minutes for release of iodine. Titrate with N/40 sodium thiosulfate stock solution, adding 1 ml. of starch indicator solution to the flask when the yellow color has nearly disappeared and continuing until the blue color is discharged. Run a duplicate to check. The volume in ml. of chlorine water needed to dose a 1-liter water sample with 1 p.p.m. chlorine is calculated from the formula:

$$\frac{\text{ml. chlorine water per 1 p.p.m. dose (in a 1 liter sample)}}{1} = \frac{11.3}{\text{ml. N/40 sodium thiosulfate solution}}$$

If gaseous chlorine is not available, a solution containing 14.2 g. of HTH per liter is prepared, settled overnight, decanted, diluted 1 to 10, and standardized as above.

**Procedure.** Set up a series of about 10 one-liter water samples, preferably raw water but occasionally treated or filtered water if superchlorination or break-point chlorination is contemplated late in the plant. Add increasing doses of the standardized chlorine water to successive samples to provide doses from 1 to 10 p.p.m. or more chlorine; mix thoroughly while introducing the chlorine solution. Allow the chlorinated samples to stand for various contact periods, say 10 minutes, 1 hour, 3 hours, 12 hours, or a length of time equal to the detention period in the plant basin or clear well. Then stir, remove from each a 100 ml. portion and titrate with the weak sodium thiosulfate solution. To do this, add 1 ml. of potassium iodide solution, stand several minutes, then proceed with the titration. Add 1 ml. of starch solution when the yellow iodine color is nearly gone, and continue the titration until the blue starch coloration disappears. From the reading of the buret:

$$\text{p.p.m. residual chlorine} = \frac{\text{ml. dilute thiosulfate solution}}{\text{ml. chlorine water}} \times 11.3$$

Also run an orthotolidin test on each sample, noting the magnitude of the residuals and the dosage at which the full

color development is practically instantaneous. Plot a set of curves between dose and residuals found following each period of contact; from this graph, a break-point if present may be located.

Dechlorinate a convenient volume of the chlorinated samples by adding sufficient sodium thiosulfate solution, as indicated by the titration for residual chlorine, and observe its taste and odor in comparison with the original water.

### pH

**Principle.** A symbol used to designate the relative acidity or basicity of a water solution as measured on a certain fundamental scale is called pH. This scale extends from zero to 14; its midpoint 7 indicates a condition of neutrality. pH numbers below 7 indicate acidity and those above 7 a condition opposite in character to acidity, namely basicity or alkalinity. The further a pH value departs from neutrality, the more pronounced the condition of acidity or basicity. As this scale is logarithmic, a difference of one pH unit between two water samples indicates that the one with the lower pH is ten times more acid in character than the other.

Natural waters have pH values ranging from about 5.5 to 8.5. During excess lime treatment, pH readings may approach 11.0. In all chemical and biological processes associated with water supply, pH value is important.

One convenient method for measuring pH depends upon the property of a dye to change its color according to the pH of the solution in which it is dissolved. Ordinarily, a dye has a decided color below a certain pH but changes to another type of color above a somewhat higher pH. Between these two pH values, the color varies in a definite manner characteristic of the dye and dependent upon the pH. This useful range through which an indicator may measure pH values is about 1.8 pH units wide for most dyes. In order to cover the whole desired portion of the pH scale, a number of different dyes are pro-

vided whose useful ranges overlap slightly. So-called wide-range indicators are useful in determining the approximate range in which an unfamiliar sample falls; for a precise pH reading only the narrow-range indicator, applicable to this region, should be used.

Standard colors, corresponding to any desired pH, are usually purchased in a comparator set. These are prepared by adding a measured amount of indicator dye to solutions of known stable pH, termed buffers. In use, a measured portion of indicator is added to a certain volume of water sample and the color compared with the colored buffer standards. Some comparators contain colored glass discs with which to make the match. As liquid standards are slowly affected by exposure to light, they should be kept in a box when not in use, and replaced every two years. Indicators cannot be used to measure the pH of highly colored or turbid water. Free chlorine residuals, above the break-point, bleach out the color. Other errors may affect the accuracy of the indicator method.

pH may also be measured by an electrical method based on the fact that the voltage between two electrodes varies according to the pH of the water in which they are immersed. This voltage is measured on a vacuum tube voltmeter calibrated to read directly in pH. The electrical method is quick and accurate; it serves as a basis for standardizing the less expensive indicator method. Measurements may be made in the presence of strong oxidizing agents.

**Solutions.** Indicator solutions for the colorimetric method, buffer, and potassium chloride solutions for the electrical method are usually purchased from concerns specializing in their preparation.

## INDICATOR METHOD

**Procedure.** Fill the comparison tube to the mark with the water sample. Add a dropperfull of indicator solution and

mix vertically with a knobbed-end glass tube, being careful to avoid entraining air bubbles. Place the tube in the comparator and find the best color match. If the test color lies between two standards, estimate the reading to the closest 0.1 pH unit. Should the color match lie at the end of the standard set, repeat the test using the next indicator, as end-matches are subject to wide error.

## GLASS ELECTRODE METHOD

**Procedure.** First adjust the voltmeter by means of a standard phthalate or other buffer, and correct for asymmetry potential according to the manufacturer's directions.

Flush out the cell with a portion of the water sample, renew the salt bridge junction, and refill the cell with the test sample. Insert the glass electrode and press the proper button for a pH reading on the dial.

## ALKALINITY

**Principle.** Carbonates, bicarbonates, hydroxides and infrequently other compounds dissolved in natural and treated waters have the property of reacting with an acid. Since any substance which neutralizes an acid must be its opposite or alkaline in nature, the measure of the acid-combining capacity of a water is termed its alkalinity. Alkalinity due to bicarbonates is important in lime softening, as this value largely determines the lime dosage.

In the determination of alkalinity, a measured sample of water is titrated with a standard acid, that is, one of accurately known concentration, in the presence of an indicator solution. This indicator is a dye which changes color abruptly at the equivalence or end-point of the titration because of the effect of added acid on the pH of the titration mixture. The two indicators used in alkalinity titrations are phenolphthalein and methyl orange, dyes which change color at pH values near 8.3

and 4.3, respectively. Ordinarily the phenolphthalein and methyl orange end-points are recorded directly as such. The methyl orange alkalinity is generally termed the total alkalinity. Most well waters, being appreciably below pII 8.3, do not have a phenolphthalein alkalinity. In water containing hydroxides or carbonates, phenolphthalein is purple; it becomes colorless when sufficient acid is added to neutralize any hydroxide and to convert the carbonates into bicarbonates. Methyl orange is yellow in the presence of bicarbonates, carbonates or hydroxides, but changes to red when these are completely neutralized. From these relations the separate content of bicarbonate, carbonate and hydroxide is frequently calculated as shown in Table 15. However, this customary calculation is not precise in the light of modern theory.

### Solutions

#### 1. Sulfuric acid, N/50.

This solution should contain 0.98 g. of concentrated sulfuric acid (0.555 ml. of 96% c.p. sulfuric acid) per liter, and should be standardized by titration against pure sodium carbonate. Since its preparation requires some analytical skill, the N/50 sulfuric acid solution is ordinarily purchased from a reliable chemical supply house.

#### 2. Phenolphthalein indicator solution.

Dissolve 1 g. of phenolphthalein in 200 ml. of 50% ethyl alcohol. Neutralize to a faint pink color with a very weak (about N/50) sodium hydroxide solution.

#### 3. Methyl orange indicator solution.

Dissolve 0.5 g. of methyl orange in a liter of distilled water.

## PHENOLPHTHALEIN ALKALINITY

**Procedure.** Add 4 drops of phenolphthalein to a 100 ml. water sample contained in a 250 ml. Erlenmeyer flask and hold over a white background. If a purplish color forms, add  $\frac{N}{50}$  sulfuric acid from a buret until the color disappears.

$$\text{Phenolphthalein alkalinity, p.p.m. as calcium carbonate} = \\ \text{ml. } \frac{N}{50} \text{ acid} \times 10$$

## TOTAL ALKALINITY

**Procedure.** Into the residue from the above titration, or to a fresh 100 ml. sample, add 3 drops of methyl orange indicator and continue to add  $\frac{N}{50}$  sulfuric acid until the yellow coloration just changes to a faint red.

$$\text{Methyl orange alkalinity, or} \\ \text{total alkalinity, p.p.m. as calcium carbonate} = \\ \text{total ml. } \frac{N}{50} \text{ acid} \times 10$$

**Arbitrary Expression as Forms of Carbonate.** In any mixture, only two forms of alkalinity compounds are assumed to be present; these are considered to be either bicarbonates with carbonates or carbonates with hydroxide. Likewise if free carbon dioxide is present, the alkalinity is commonly taken to be all in the form of bicarbonates. More modern interpretation disregards this system and bases the distribution of alkalities on the relations between pH and total alkalinity. Nevertheless for calculating lime requirements for softening or in similar problems involving simple balancing of chemical equivalents, both modern and older methods yield the same results. But in problems involving actual concentrations of the various members of the carbon dioxide-bicarbonate-carbonate-hydroxide group, only the more precise theory should be used. The obsolescent method is retained in Table 15 merely for its simplicity and long-established usage; its errors start near pH 7.7 and increase with higher pH values.

TABLE 15

Types of Alkalinity from Titration Results

| Phenolphthalein<br>Alkalinity | Methyl Orange<br>Alkalinity | Bicarbonate | Carbonate | Hydroxide |
|-------------------------------|-----------------------------|-------------|-----------|-----------|
| P = O                         | M                           | M           | O         | O         |
| P = less than $\frac{1}{2}$ M | M                           | M-2P        | 2P        | O         |
| P = $\frac{1}{2}$ M           | M                           | O           | 2P        | O         |
| P = more than $\frac{1}{2}$ M | M                           | O           | 2(M-P)    | 2P-M      |
| P = M                         | M                           | O           | O         | M         |

*Example.* For a water whose phenolphthalein alkalinity = 15, and total alkalinity = 28: P is more than  $\frac{1}{2}$  M; therefore, bicarbonates are absent and carbonates are  $2(28 - 15) = 26$ ; hydroxide alkalinity is  $(2 \times 15) - 28 = 2$ . As a check, the sum of the carbonate plus the hydroxide,  $26 + 2 = 28$ , equals the total alkalinity.

## CARBON DIOXIDE—TITRATION METHOD

**Principle.** Water containing carbon dioxide, as from most wells and some surface sources, possesses weakly acidic properties and, therefore, reacts with alkali. In the test, a measured amount of water is titrated by a standard alkali solution using phenolphthalein as an indicator to mark the completion of the neutralization.

**Solutions**1. Sodium hydroxide  $\left(\frac{N}{44}\right)$ 

This solution contains 0.91 g. of sodium hydroxide per liter. Since its preparation presupposes some analytical skill, many laboratories will purchase this item from a specialty house.

## 2. Phenolphthalein indicator.

Prepare as for the alkalinity test.

**Procedure.** To a 100 ml. water sample in a Nessler tube or graduate cylinder held over a white background, add 10 drops of phenolphthalein indicator and titrate rapidly with  $\frac{N}{44}$  sodium



hydroxide until a faint purple forms. Stir as required to keep the coloration uniform by gently inverting the tube in such a manner that no air bubbles are caught and swept through the water column.

When waters are high in carbon dioxide, repeat the test after first placing approximately the amount of  $\frac{N}{44}$  alkali needed for titration at the bottom of the tube in order to reduce the loss of carbon dioxide to the air.

$$\text{Carbon dioxide, p.p.m.} = \text{ml. } \frac{N}{44} \text{ alkali} \times 10$$

### CALCULATION METHOD

Usually carbon dioxide is more accurately calculated from total alkalinity and pH value than it can be determined by titration. The accompanying chart, Figure 46, based on theoretical relations, enables carbon dioxide to be read off the bottom scale underneath the point where the pH diagonal intersects the total alkalinity.

*Example.* A well water has a pH value of 7.0 and alkalinity of 120 p.p.m. What is its carbon dioxide content?

**Solution.** Find the 120 p.p.m. alkalinity position on the bottom scale and line this point vertically upward until it intersects with the diagonal marked 7.0. Project the intersection horizontally to the right and read 25 p.p.m. carbon dioxide.

### CALCIUM CARBONATE STABILITY

**Principle.** The object of this test is to ascertain whether a water sample is saturated with calcium carbonate in connection with corrosion control, as explained in Chapter 12. Some powdered, chemically pure calcium carbonate is placed in a sample bottle full of water and agitated for several hours, then allowed to stand until clear. A portion of the supernatant or clear top liquid is removed for pH and alkalinity tests, and the

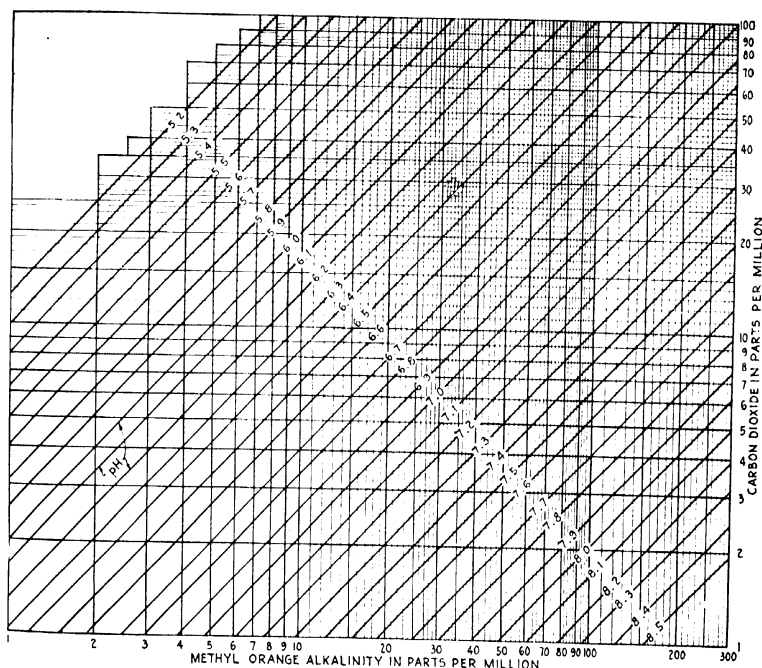


FIGURE 46

Relation between Total Alkalinity, pH and Carbon Dioxide

(Courtesy of Buck, Selfert and Jost, New York, N. Y.)

result compared with the tests on the original sample. If the alkalinity and pH has decreased, some dissolved calcium carbonate must have plated out on the powder from a super-saturated solution. The same tendency will prevail in a pipe-line to establish a protective carbonate coating. If the alkalinity and pH have increased, some aggressive carbon dioxide must have been present in the water to dissolve some of the powder. In a pipe-line, this activity will destroy or prevent formation of

a protective carbonate coating and so the pipe will be subject to corrosion by dissolved oxygen. If contact with the powder produces no change in alkalinity or pH, the water is stable with respect to calcium carbonate and will neither attack nor deposit a carbonate film.

### **Reagents**

1. Calcium carbonate contact bottles.

Place about 2 teaspoonfuls of chemically pure calcium carbonate powder into an 8-ounce glass-stoppered bottle. Wash repeatedly with portions of the water to be tested, settle several minutes and pour off the supernatant, which may still be turbid. Prepare two bottles in this manner, one for a check.

2. Sulfuric acid  $\frac{N}{50}$ .

3. Methyl orange indicator.

**Procedure.** Fill the bottle containing washed calcium carbonate powder with the water sample and insert the stopper without allowing an air bubble to remain. Shake to suspend the powder throughout the liquid, set aside and again shake at intervals for several hours. With very aggressive waters, the shaking period may be shortened if only comparative results are desired. Finally, allow the bottle to stand about eight hours to settle out the suspended powder. During the early part of the settling period, knock the bottle gently and twist the stopper so that powder attached to the walls or stopper area is detached and permitted to settle. Any powder allowed to remain in suspension will void the titration. Withdraw carefully by pipette a 100-ml. sample of the clear supernatant and titrate for total alkalinity. If a glass electrode is available, run a pH test also. Do not filter the liquid because exposure to air lowers the pH value of stabilized water perceptibly.

This test may be run continuously by passing water slowly through a 5-foot closed glass tube filled with calcium carbonate powder. The effluent water filters through a sintered glass funnel enclosed inside the packed tube and discharges through

a cell containing the glass electrode assembly to empty finally below the surface in a sampling flask used to determine the alkalinity.

### **Interpretation**

Decrease in pH or alkalinity—tendency to form a protective deposit or coating; non-corrosive.

Increase in pH or alkalinity—tendency to dissolve a previously laid carbonate film; corrosive.

No change in pH or alkalinity—stable; will not corrode if a film is already present.

## **QUALITATIVE CORROSION TEST— SPOT PLATE METHOD**

**Procedure.** Allow water to drip slowly from a faucet to a rough white porcelain tile, a piece of white china tableware roughened by grinding compound will do. If the water is corrosive, a red stain will appear on the spot plate.

## **HARDNESS, CALCIUM AND MAGNESIUM— SOAP METHOD**

**Principle.** Soap solution of known strength is titrated into a water sample. The hardness, present as salts of calcium, magnesium, and less frequently iron, combines with the soap to form curds. No permanent suds can form until all the soap-consuming substances are removed in the precipitate. By noting the volume of soap solution required to reach the point of permanent lathering, a measure is obtained for the total hardness of the sample. The effect of iron, carbon dioxide, or excess acidity can be eliminated by adjusting the pH to a faint pink phenolphthalein color.

By blocking out the soap-consuming power of magnesium with ammonium chloride at a high pH value, only the calcium remains for soap titration, thus providing a means to distinguish between the calcium hardness and the magnesium hard-

ness. The latter value is obtained by difference. At this high pH, interference from iron is also eliminated.

### Solutions

1. Standard soap solution, 1 ml. = 1 mg. calcium carbonate.

Directions for preparation of this solution are given in *Standard Methods of Water Analysis*. Operators will usually profit by ordering this solution from a specialty concern specifically engaged in supplying water laboratories. More faulty samples of standard soap solution are usually purchased inadvisedly by water plants than any other analytical solution. A solution of pure castile soap in isopropyl alcohol is favored; the soap does not separate from solution on aging or in cold weather.

2. Sodium hydroxide, 1.0 N (approx.)

Dissolve 10 g. of sodium hydroxide in a small volume of water. Cool and set aside overnight in a stoppered bottle. Pour off the clear supernatant liquor into a Pyrex glass bottle, without disturbing the sediment. Dilute to 250 ml. and shield from air with a rubber stopper. Insert a dropper through the stopper, with a mark to deliver 2.8 ml.

3. Hydrochloric acid, 1.0 N (approx.)

Pour 23 ml. of concentrated hydrochloric in a small amount of distilled water and dilute to 250 ml. Use this solution from a dropping bottle.

4. Phenolphthalein indicator.

See directions under alkalinity test.

5. Ammonium chloride solution (10%).

Dissolve 10 g. of chemically pure ammonium chloride in distilled water to produce 100 ml. of solution.

## TOTAL HARDNESS

**Procedure.** Measure 50 ml. of water sample into a glass-stoppered 8-ounce bottle. Add 2 drops of phenolphthalein indicator and adjust to a faint pink with sodium hydroxide solution.

Titrate with standard soap solution, adding 0.5 ml. at a time, vigorously shaking the bottle between each addition until near the permanent lathering point. At this stage add the soap in decreasing steps, finally approaching the lather-point with single drops.

The end-point is considered reached when an unbroken lather will persist for five minutes after laying the bottle on its side. Add 0.2 ml. more of soap solution to check, as with some waters a false end-point or a "ghost-point" prematurely appears; it is destroyed by a slight addition of soap. Continue the titration until a permanent suds blanket is formed; one that is stable on further slight addition of soap.

Repeat the soap titration as above, but using distilled water as a blank. The reading so obtained is known as the lather factor.

When testing waters, alkaline to phenolphthalein, their pH is adjusted to a faint pink color by dropping in hydrochloric acid.

If more than 15 ml. of soap is needed, repeat the test on a dilution of the water sample.

$$\begin{aligned} \text{Total hardness, p.p.m. as calcium carbonate} = \\ (\text{ml. soap solution} - \text{lather factor}) \times 20 \end{aligned}$$

## CALCIUM AND MAGNESIUM

**Procedure.** Measure out 57 ml. of water sample and adjust as before to the phenolphthalein end-point by adding dropwise sodium hydroxide solution or hydrochloric acid solution as required. Then add 1 ml. of ammonium chloride solution and 2.8 ml. of sodium hydroxide. The pH of the mixture should be between 11.7 to 12.0.

Add soap solution from the buret, shaking vigorously and laying the bottle on its side after each portion until a lather persists over the entire surface for 1 minute. Repeat the titration using distilled water as a blank. The reading so obtained is the lather factor for this test.

If more than 7 ml. of soap solution is required, repeat the test on a diluted sample.

$$\begin{aligned} \text{Calcium hardness, p.p.m. as calcium carbonate} &= \\ &(\text{ml. soap solution} - \text{lather factor}) \times 20 \\ \text{Magnesium hardness, p.p.m. as calcium carbonate} &= \\ \text{Total hardness, p.p.m. as calcium carbonate,} & \\ - \text{Calcium hardness, p.p.m. as calcium carbonate} & \end{aligned}$$

### TOTAL HARDNESS BY CALCULATION

If an analysis in the so-called ionic form is available, the hardness of a water sample may be calculated from the following relation:

$$\begin{aligned} \text{Total hardness, p.p.m. as calcium carbonate} &= \\ 2.497 \times \text{p.p.m. calcium} + 4.115 \times \text{p.p.m. magnesium} & \end{aligned}$$

*Example.* A water contains 55 p.p.m. calcium and 40 p.p.m. magnesium. What is its total hardness?

*Solution*

$$\begin{aligned} \text{Calcium hardness} &= 2.497 \times 55 &= 137.4 \\ \text{Magnesium hardness} &= 4.115 \times 40 &= 164.5 \\ \text{Total hardness, p.p.m. as calcium carbonate} &= 301.9 \end{aligned}$$

### TURBID WATERS—JACKSON TURBIDIMETER

**Principle.** Turbidity in water is caused by finely divided matter, usually soil particles in suspension. Since turbidity obstructs the passage of light, this property is used to measure the amount of turbidity in a sample. In the Jackson turbidimeter, light from a standard source, either a candle or a flash-light bulb, passes up through a water column contained in a graduated tube. This column is increased in depth until the view of the light is obscured, and a reading is then taken directly from the tube. This reading is expressed in terms of silica because soil grains are mostly silica and because early turbidity measurements were made by comparing the sample

with bottled standards of silica suspensions. Bottle standards are not favored because of the difficulty in their preparation and standardization and also their impairment, on standing, by algae and the action from alkalinity of the glass.

No definite relation exists between the weight of suspended matter and the turbidity of the suspension. The fineness of division of the particles greatly influences their light-obscuring characteristics.

**Procedure.** Light the candle or bulb; shake the sample bottle to suspend the particles uniformly and pour down the turbidimeter tube. Continue to pour the sample until the outline of the flame or filament is diffused out. A hazy illuminated surface marks the correct depth. Remove the tube and read the turbidity in p.p.m. of silica directly from the scale.

Two tubes are provided, one for measuring turbidities from 100 to 4000 p.p.m. and the other to read from 25 to 100 p.p.m. These tubes should be kept clean, inside and outside; any soot from the candle flame must be removed. Always remove the charred tip from the candle before a test and see that the distance from the flame to the tube is constant. Readings should be made quickly as the flame becomes larger after burning a few minutes.

## CLEAR WATERS—HELLIGE TURBIDIMETER

**Principle.** Residual turbidity in clear waters, such as filter effluents, does not obstruct light sufficiently to be measured by the Jackson turbidimeter described above. Slightly murky waters have the property of scattering light. In the Hellige instrument scattered light from sidewise illumination of the sample is compared with transmitted light passing upward through the cell. A shutter in the device is adjusted until the light from both paths is equal in intensity. The shutter dial is then read and the turbidity is obtained from a calibration curve furnished with the instrument.



Standard suspensions for direct comparison of low turbidities are unreliable, unless prepared fresh every few days or weeks. For results of highest precision a photo-electric cell turbidimeter is employed.

**Procedure.** Pour the sample in a cell, place on cover and mount on the platform. Close the door, light the bulb, and adjust the shutter so that both fields of view in the ocular match. Note the dial reading and obtain the turbidity from the curve.

Four different cells and two filters are provided to enable readings from 0 to 150 p.p.m. turbidity.

### COLOR—COMPARATOR METHOD

**Principle.** Color of a water is due mainly to the organic matter in solution, such as decomposed vegetation and similar substances. The apparent color due to precipitated iron or variously colored turbidity should first be removed by filtration before judging the true color of a sample.

Standard colored solutions containing potassium chloroplatinate and cobalt chloride may be prepared for matching, but colored glass discs are much more convenient to use.

**Procedure.** Place a clear sample, filtered or centrifuged if necessary, in the glass cell of the comparator and turn the disc in which the glass standards are molded until the best color match is obtained.

### ODOR THRESHOLD

**Principle.** Objectionable odors in water are caused by small amounts of organic matter, living or dead, from algae, vegetation or soils; or by various types of wastes, domestic or industrial. The intensity of an odor depends upon the nature of the substances responsible and their concentration. In testing, no attempt is made to identify the materials producing the odor, other than to describe broadly the type of odor by some adjective like musty, aromatic, oily, grassy, woody, etc.

The intensity of odor is expressed by a figure representing the number of times a sample can be diluted with odor-free water before the sensation becomes too faint for detection. The point at which the odor is barely perceptible is termed the threshold.

Odor depends primarily on the slow escape, by evaporation, of the smell-producing materials from the water. Consequently, heating the sample to promote evaporation will intensify the odor. In some cases odors undetected at ordinary water temperatures will be evident if the water is warmed before smelling. This property enables an odor to be evaluated when the cold water is apparently odor free, thus allowing an operator to detect a developing odor condition. The hot odor threshold is ordinarily three to eight times the cold odor threshold. The temperature used for hot odor determinations should not be so warm as to injure the nasal passages when sniffing.

### **Solutions**

#### **1. Odor-free water.**

Pass tap water through a 2-inch diameter glass tube, five to six feet long, packed with granular activated carbon. (Activated carbon dealers furnish sufficient material to charge a tube, if requested.) Water should be passed through at such a rate that a thin stream leaves through a small tube outlet inserted through a rubber stopper at the top of the column. Before being used to prepare dilutions, the effluent should be run until odor-free when tested warm. Some tap water may be freed from odor by boiling away 15% of its volume.

**Procedure.** Place 250 ml. of water sample, or a dilution with odor-free water, in a 500-ml. glass-stoppered Erlenmeyer flask. For a cold test, maintain a temperature between 70 to 75°F. Shake vigorously for 2 to 3 seconds, remove the stopper, and inhale with the nose held right at the mouth of the flask. Some operators use a nosepiece, made from a test tube, to reach down near the surface of the water. If an odor is detected, prepare a weaker dilution and repeat the test until the

odor can no longer be distinguished with certainty. In case of doubt, compare the test dilution with a flask containing only odor-free water.

For hot odor threshold determination, run the test as above but heat the stoppered dilution to 140°F. before sniffing. Place the thermometer into a dummy instead of the test dilution.

The first sniff after removing the stopper contains the greatest concentration of odor. Second and later shakings are successively weaker in odor. Tobacco smoking and odors on the fingers interfere with the test. The flasks can best be handled with tongs. Flasks should be boiled with odor-free water before using for a test. Tests should be run immediately after preparing a dilution. These tests should not follow closer than an hour after meals.

Dilutions should be prepared systematically in order to reduce lost motion. The accompanying schedule is suggested for testing an unfamiliar sample whose approximate threshold value is unknown. If the sample has an odor, use the dilutions in the first column of Table 16. Find the interval where the test changes from positive to negative; then prepare the dilutions in the second column opposite this interval. From the most dilute mixture giving an odor, calculate the odor threshold by the formula:

$$\text{Odor threshold} = \frac{\text{ml. sample in dilution}}{250}$$

In the table, odor threshold numbers are given for various dilutions. Odors may be quickly evaluated if the operator has several flasks with which to work at the same time.

*Example.* If the 65 ml. dilution gave an odor while the 16 ml. dilution did not, prepare the next series of dilutions to contain 45, 30 and 22 ml. respectively, of water sample. If the 45 ml. dilution shows odor, and the weaker mixtures do not, the threshold odor is 5.6. If all the last three dilutions are negative, the odor threshold is 4.0.

The divisions in this table are based on a physiological law which relates response with intensity of stimulus; the steps are, therefore, logarithmic. A closer spacing of test dilutions imposes decisions beyond the precision of the nose as a measuring instrument, and prolongs the test to fatigue the operator. The accompanying table, based on a 40% threshold difference (approximately 30% dilution), will express an odor with sufficient accuracy for most purposes. With this system, the threshold number is reached in two steps, each involving three dilutions and the blank. After practice, the operator may adopt a table of dilutions having narrower differences and employing more flasks. For unprejudiced results, the sniffer should not know the identity of the flasks, which are better prepared by an assistant.

TABLE 16

## Dilution Schedule for Odor Threshold Test

If the sample has an odor, dilute the volumes shown below to 250 ml. in a 500 ml. glass-stoppered Erlenmeyer flask. Three flasks are needed for dilutions, and one for the odor-free water blank.

| First Dilutions   |                       | Second Set of Dilutions |                       |
|-------------------|-----------------------|-------------------------|-----------------------|
| <i>Sample ml.</i> | <i>Odor Threshold</i> | <i>Sample ml.</i>       | <i>Odor Threshold</i> |
| 250               | 1.0                   |                         |                       |
|                   |                       | 175                     | 1.4                   |
|                   |                       | 125                     | 2.0                   |
|                   |                       | 90                      | 2.8                   |
| 65                | 4.0                   | 45                      | 5.6                   |
|                   |                       | 30                      | 7.9                   |
|                   |                       | 22                      | 11.0                  |
| 16                | 16                    | 11                      | 22                    |
|                   |                       | 8.0                     | 32                    |
|                   |                       | 5.5                     | 45                    |
| 4.0               | 64                    | 2.8                     | 86                    |
|                   |                       | 2.0                     | 125                   |
|                   |                       | 1.4                     | 175                   |

## TOTAL DISSOLVED IRON

**Principle.** In natural water, dissolved iron is mainly in the unoxidized condition; once allowed to oxidize all but a very small amount of oxidized iron will precipitate. This test is made on a clear sample, filtered if necessary. In the test all the iron is oxidized in strongly acid solution, from which it will not precipitate. Potassium thiocyanate solution is then added to form a deep red color which is matched with standards. Liquid standards may be *freshly* prepared in Nessler tubes but for greatest convenience a set of colored glass discs should be available.

**Solutions**

1. Potassium thiocyanate.

Dissolve 5 g. of potassium thiocyanate in distilled water and dilute to 250 ml.

2. Nitric acid, 6N.

Dilute 191 ml. of concentrated nitric acid to 500 ml. with distilled water.

3. Potassium permanganate.

Dissolve 3.15 g. of potassium permanganate in distilled water and dilute to 500 ml.

**Procedure.** Measure out 50 ml. of water sample and 5 ml. of nitric acid in a 250 ml. Erlenmeyer flask. Boil 5 minutes, add 3 drops of potassium permanganate or until a permanent faint pink persists. Cool and add 5 ml. of potassium thiocyanate; mix, place in a comparator cell and match with color standards immediately.

If the sample is high in dissolved iron, use a smaller volume, dilute to 100 ml. and proceed as above. Multiply the result by the proper dilution factor.

Water containing organic matter should first be evaporated, then the residue baked sparingly. It is then dissolved in 10 ml. of nitric acid and the test continued as above. If iron in suspen-

sion also is to be included, this evaporation step is conducted on the unfiltered sample.

## DISSOLVED OXYGEN

**Principle.** Oxygen is absorbed from solution in water by means of freshly precipitated manganous hydroxide which compound is formed when the manganous sulfate reagent strikes the water sample previously causticized with an alkaline solution of potassium iodide. After the mixture is acidified, the higher oxide of manganese, formed with the dissolved oxygen, liberates an equivalent amount of iodine from potassium iodide. The iodine so released is titrated with sodium thiosulfate to measure the original oxygen content. Starch is used as an indicator; until the end-point is reached, an intense blue color is produced with iodine. When all the iodine is reduced by the thiosulfate solution, the titration mixture becomes colorless.

The presence of nitrites, sulfites, ferric iron, some organic compounds, and sulfur compounds contained in chlorinated wastes interfere with the dissolved oxygen test and so require a preliminary removal. Ordinarily when testing tap water, these interferences are absent; here only the oxygen fixation and titration by the so-called simple Winkler method suffices.

Streams and reservoirs may contain over 0.1 p.p.m. of nitrites; for this case, a number of preliminary procedures are available, the simplest of which, the sulfamic acid method is given below.

### Solutions

#### 1. Manganous sulfate.

Dissolve 240 g. of manganous sulfate in distilled water and dilute to 500 ml.

#### 2. Alkaline potassium iodide.

Dissolve 350 g. of potassium hydroxide or 250 g. of sodium hydroxide and 75 g. of potassium iodide in distilled water and dilute to 500 ml.

3. Sodium thiosulfate solution, N/40.

Dissolve 6.205 g. of chemically pure sodium thiosulfate in recently boiled and cooled distilled water; dilute to 1 liter. This solution loses strength after a few weeks standing. Add 5 ml. chloroform as a preservative.

4. Concentrated sulfuric acid.

5. Starch solution.

Grind a small amount of potato starch into a thin paste with a few ml. of cold water; pour while stirring into about 250 ml. boiling water. When cool, preserve with a few drops of chloroform.

6. Sulfamic acid solution.

Dissolve 4 g. of sulfamic acid in 50 ml. of distilled water; then add 50 ml. of cold 40 per cent sulfuric acid. Any slight turbidity is unimportant.

**Sampling.** Collect 250 to 300 ml. of sample in a glass-stoppered bottle out of contact with the air. Tap water is sampled through a rubber tube extending from the faucet to near the bottom of the bottle; water is delivered through this submerged inlet in sufficient quantity to sweep out the bottle volume about 5 to 10 times. The hose is carefully withdrawn with water overflowing slowly, and the glass stopper eased into place without allowing a bubble to be trapped.

If the sample is discharged by free fall from the faucet to the bottle, some oxygen will always dissolve from the air, unless the water is saturated, and so invalidate the test.

Samples are taken from open containers or reservoirs in a bottle provided with two tubes inserted through a two-hole rubber stopper. One tube extends nearly to the bottom of the bottle, and is for the entry of water; the other, a short one, barely passes through the stopper and is connected to some larger vessel or trap to which suction is applied. The sample bottle is submerged where depth is sufficient; otherwise, a hose is placed on the water inlet tube and stretched to reach beneath the surface of the water in the conduit. On applying suction

to the trap bottle, the sample bottle is flushed out with water until the trap becomes filled. In sampling streams and reservoirs, the sample bottle may be conveniently contained inside the larger trap bottle as shown in Figure 47.

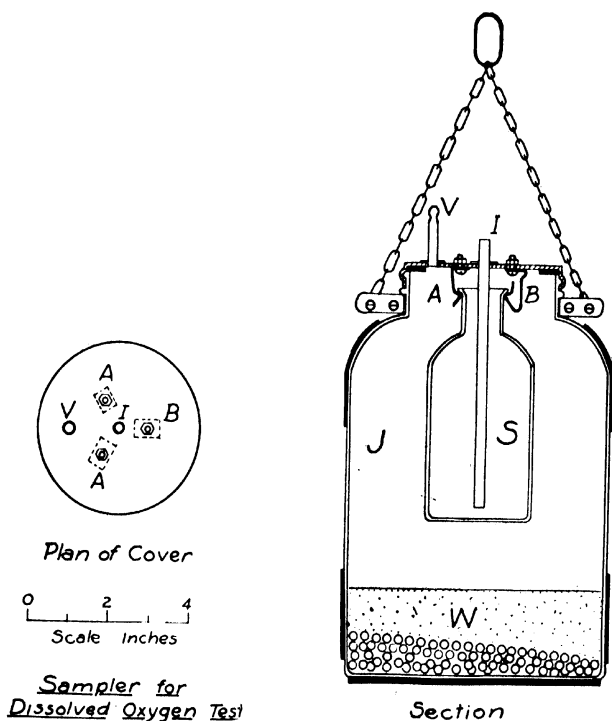


FIGURE 47

#### Sampler for Dissolved Oxygen Test

In the 1 gallon jar J is suspended a 250 to 300-ml. sample bottle S; spring clips A, B hold the sample bottle to the reservoir screw cap. A weight W sinks the assembly. Water enters through inlet tube I and displaces air through the vent V.

(Courtesy of *Sewerage Works Journal*, Chicago, Ill.)



A test should be run immediately upon collection, except where sulfamic acid is added; in this case, the sample may be allowed to stand several hours.

**Procedure.** Add reagents by means of a pipette whose tip is submerged just below the water level in the neck of the bottle. Replace the stopper, settling in place by its own weight, so that air bubbles are excluded.

Add 1 ml. of sulfamic acid reagent; shake by inverting the bottle; and allow to stand 10 minutes. When water is low in nitrites, as with most tap waters, this step is omitted.

Add 1 ml. of manganous sulfate solution, mix by inverting the bottle; then add 3 ml. of the alkaline potassium iodide reagent, mix, and allow the precipitate to settle. Add 1 ml. of concentrated sulfuric acid; mix to dissolve the precipitate completely. Transfer 200 ml. of the mixture to a 300-ml. Erlenmeyer flask and titrate with N/40 sodium thiosulfate. Add 1 ml. of starch indicator when the yellow iodine color becomes faint, and continue adding the sodium thiosulfate until the blue color just disappears. The number of ml. of sodium thiosulfate used equals the parts per million of dissolved oxygen.

## OXYGEN CONSUMED

**Principle.** Organic matter dissolved in water may be oxidized, more or less completely, by means of an oxidizing agent, like potassium permanganate. Since the reaction is aided by elevated temperature, this test is usually made in a hot water bath. Following the digestion of the sample with excess permanganate, this excess is destroyed by an excess of reducing agent, ammonium oxalate, and the mixture is titrated back with more permanganate.

This test is valuable in determining any gross changes in the organic matter content of a water. A considerable change in this figure from the normal should always be explainable, otherwise the water may be suspected as unsafe. In conjunction with

other determinations, poison gases and other organic contaminants may be indicated by a sudden increase in this test. This application is discussed at the end of the chapter.

### Solutions

#### 1. Dilute sulfuric acid.

Add 100 ml. of concentrated sulfuric acid to 300 ml. of distilled water.

#### 2. Ammonium oxalate solution.

Dissolve 0.8880 g. of ammonium oxalate in distilled water and dilute to a liter. As this solution is unstable, it should be prepared fresh monthly.

#### 3. Standard potassium permanganate solution.

Dissolve 0.4 g. of chemically pure potassium permanganate in 1 liter of distilled water. Take 10 ml. of this solution and add, with 10 ml. of dilute sulfuric acid, to 100 ml. of distilled water. Digest 30 minutes in a boiling water bath. Add 10 ml. of the standard ammonium oxalate, and titrate to a faint pink coloration with potassium permanganate solution. Adjust the permanganate solution so that 1 ml. is equivalent to 1 ml. of ammonium oxalate solution; it will then be equivalent to 0.1 mg. of chemically available oxygen. Preserve in a dark bottle and restandardize every few months.

**Procedure.** Place a 100-ml. water sample, or a smaller portion diluted to 100 ml. in the case of polluted sources, in a 300-ml. Erlenmeyer flask; add 10 ml. of potassium permanganate solution and 10 ml. of dilute sulfuric acid. Immerse the flask to a high level in a bath of boiling water for 30 minutes. Add 10 ml. of ammonium oxalate solution and titrate back while still warm with standard potassium permanganate to a faint pink color. Repeat the procedure on a distilled water blank in order to correct for the reagent. In all cases, not less than a 5-ml. excess of potassium permanganate solution should remain after the digestion.

The net volume of permanganate used equals the amount used for the sample minus that used for the blank.

Oxygen consumed, p.p.m. = net ml. of potassium permanganate  
solution  $\times \frac{100}{\text{ml. sample}}$

## CHLORIDE

**Principle.** Chlorides are titrated with silver nitrate; a white precipitate of silver chloride is formed, thus removing the chloride radical from solution. Sodium chromate is added to indicate the end-point. After all the chlorides have reacted, the first excess of silver nitrate solution combines with the chromate to form a clay red coloration and precipitate of silver chromate.

### Solutions

1. Standard silver nitrate solution.

Dissolve 2.40 g. of silver nitrate crystals in 1 liter of distilled water. To standardize: titrate against a salt solution, containing 1.648 g. of pure sodium chloride per liter, and adjust by dilution. To combine with 5 ml. of the standard salt solution 5 ml. of silver nitrate solution are needed. Then 1 ml. of silver nitrate is equivalent to 0.5 mg. of chloride radical.

2. Potassium chromate indicator.

Dissolve 25 g. of potassium chromate in about 50 ml. of distilled water. Add silver nitrate solution until a red precipitate forms; stand a few days, then decant the clear yellow top portion and dilute to 500 ml.

**Procedure.** Place a 50-ml. water sample in a white evaporating dish. Adjust with dilute sodium hydroxide solution, as used in the carbon dioxide test, or with N/50 sulfuric acid, as used in the alkalinity determination, until the sample becomes colorless with phenolphthalein indicator. Add 1 ml. of potassium chromate indicator to the sample; then titrate with silver nitrate solution, constantly stirring, until a reddish coloration appears. Repeat the test on 50 ml. of distilled water to determine the blank correction, which is subtracted from the test

reading. When waters are high in chlorides, a smaller sample volume is taken, and diluted to 50 ml., with distilled water.

$$\text{Chloride, p.p.m.} = \frac{500}{\text{ml. sample}} \times (\text{ml. silver nitrate solution for test} - \text{ml. for blank})$$

## SULFATE

**Principle.** Sulfates are precipitated during titration with standard barium chloride solution in the presence of tetrahydroxyquinone (THQ) indicator. At the end-point, a slight excess of barium chloride changes the color of the indicator from yellow to rose red. The solubility of barium sulfate is reduced with isopropyl alcohol. The indicator is added as a dry powder because its solution is unstable.

### Reagents

1. Standard barium chloride solution, 1 ml. = 1 mg. sulfate.

Dissolve 2.54 g. of barium chloride dihydrate in distilled water and dilute to 1 liter. This solution should be standardized by determining its barium content gravimetrically.

2. Isopropyl alcohol.

3. THQ indicator powder.

**Procedure.** Clear samples containing less than 2,000 p.p.m. of sulfate and free from phosphates are tested by this procedure. Neutralize a 25 ml. sample if alkaline, with approximately N/40 hydrochloric acid until just acid to phenolphthalein. Add 25 ml. of isopropyl alcohol. Introduce 0.1 or 0.2 g. of THQ, using the small cup furnished with the reagent, and swirl the flask to dissolve the powder. Titrate with standard barium chloride solution, constantly agitating the flask until a rose color appears throughout the whole solution. During the test, the temperature should be kept between 68° to 78°F. Subtract 0.1 ml. as a blank in titration.

$$\text{Sulfate, p.p.m.} = (\text{ml. barium chloride} - 0.1) \times \frac{1000}{\text{ml. sample}}$$

## JAR TESTS

Jar tests are small scale experiments in which water samples are treated to resemble plant processes with the object of determining the value of various treatments before applying them in practice. These tests are used to investigate treatments for coagulation, softening, iron removal, chlorine demand and break-point, taste and odor control, corrosion control, and when conducted under sterile conditions, for bacterial removal. Jar tests should always *precede* the design of a plant so that there is no guess work or mistakes evident after starting a new installation.

Ordinarily, a jar or bottle test is used routinely to aid in the adjustment of coagulant dosage, especially in plants where the character of the raw water is subject to sudden changes. In this case, the jar test results may indicate what pH range is needed for best clarification, particularly with soft waters of low alkalinity. The actual dosage in the jar test will generally be less than that required in the plant because mixing and batch settling are superior to the corresponding steps in the plant. This is true particularly if the mixing and settling intervals are taken to equal these steps in the plant. Jar tests are especially valuable in comparing the economy of competitive materials.

The result of a jar test is judged by running the proper laboratory tests on a small portion of the treated water. Coagulation is better measured by running a turbidity test than by merely observing the clearness of the supernatant. Similarly in odor-removal tests with carbon, the settled samples should be measured for threshold odor instead of simply tasting the product. An advantage of numerical measurements is that results can be drawn on a graph for study.

**Stirring Machine.** A stirring machine is absolutely essential for all tests except for those in which simply a flash mix is sufficient before standing, as in chlorination. For coagulation tests, exactly the same mixing and flocculating action must be

maintained throughout the whole series of tests. Without uniformity in these details, the jar test is valueless and may even be misleading.

Stirring machines may be purchased from laboratory supply houses or built by the operator. Provision should be made for treating from 4 to 12 samples at the same time; the usual machine accommodates 6 bottles. The source of power for a stirring machine is usually an electric motor (1/16 to 1/4 H.P.). An automobile windshield wiper motor using a vacuum from an aspirator is frequently used. With motor drives, a grooved speed-reducing pulley for belt drive turns a jack shaft from which individual stirrer shafts are turned by means of a bevel gear. These bevel gears may be obtained from a cheap small-size hand drill. Agitator blades are simply metal strips attached to the stirrer shaft. If a windshield wiper motor is used, the to-and-fro motion is transmitted through a drag link and cranks to each stirrer. Speed control is essential: the motor drive may be varied through a set of cone pulleys and by rheostat control. A windshield wiper is controlled by the amount of vacuum.

#### **Solutions as Required**

1. Solutions of coagulant or of chlorine.
2. Suspensions of lime, or of activated carbon.

Dissolve or suspend sufficient chemical in 500 ml. of water so that 1 ml. added to the jar gives a dosage of 1 p.p.m. or 10 p.p.m. as desired. If a 1-liter water sample is used, dissolve 0.5 or 5.0 of material in 500 ml.; 1 ml. of the stock solution will then give a dosage of 1 p.p.m. or 10 p.p.m. respectively. Weights of materials for other conditions of dosing are listed in Chapter 24.

**Procedure.** In general, the sample should not be less than 1 liter, especially in tests with coagulants.

For coagulation tests, flash mix the chemical with the water, and with its contents still in agitation, set the jar under the mixing machine and stir at the maximum rate for a few minutes. Taper the stirring rate downward as floc forms and

grows, finally using the slowest speed to condition the floc. Continue as long as improvement is evident, but generally do not exceed the plant mixing time. Be sure every jar in a series of tests is given exactly the same handling, down to the smallest detail, otherwise the results are untrustworthy.

Settle to match plant retention period. For measurement of final turbidity or other tests, carefully withdraw a sample of supernatant through a siphon tube or through a perforated-bottom cup fitted with a plug or sliding closure. Careless withdrawal breaks the floc particles and increases the final turbidity readings. Plot a curve between dosage and final turbidity, thus enabling the dosage to be read off to give any desired clarity. For approximate control, a dosage may be selected for trial when it forms a well-defined, easily settling floc after mixing, flocculation and about one-hour standing.

When the jar test is intended to guide dosage of activated carbon, a stirring time is first established to equal the effective contact period available in the plant. This is done by dosing the jars to equal plant treatment, then determining the threshold odor after various periods of mixing. The carbon is filtered off through cotton which has been repeatedly washed in odor-free water, or removed in a centrifuge. The residual threshold odor is plotted against stirring time and the mixing interval selected whose result equals the threshold odor in the plant; this mixing time is used thereafter in a jar test.

Indicative results may be obtained by pouring off a portion of the dosed and mixed batches in a flask without filtering, to note the lowest treatment required to produce a palatable water.

## INDICATION OF CONTAMINATION BY POISONS

Detection of poisons in water is a specialized test which can be competently done only by skilled analysts. Due to the confidential nature of these tests, their publication is inadvisable

in a textbook whose circulation is difficult to control. If occasion arises, the State Department of Health acting for the Office of Civilian Defense, can furnish details of suitable procedures. However, by running a combination of simple routine tests, a suspected water sample can usually be cleared or held for further confirmation. Suspicious samples should always be preserved for later study. Should a water supply become fouled by a gas bomb, the operator should make certain that the gas officer transmits samples to the closest laboratory conducted by the Chemical Warfare Service for the Office of Civilian Defense.

**Principle.** The following routine tests are run on the plant effluent and on samples from the distribution system; any sudden departure from normal values show the need for a further investigation. These tests are:

*pH.*

*Residual chlorine* in systems which receive chlorination.

*Taste, odor, color, turbidity*, unusual characteristics may indicate trouble.

*Alkalinity*, some contaminants affect this value.

*Oxygen consumed*, a value of 5 p.p.m. above normal indicates the water is non-potable. When lewisite is the poison present, the titration in this test may be run on the cold sample, as lewisite combines readily with potassium permanganate solution.

*Chlorine demand*, as nearly all poisons possibly introduced into water supplies affect the chlorine demand, this test is a very valuable one. An excess of 5 p.p.m. above normal is dangerous. Obviously, this determination cannot be made if a chlorine residual is present. For details of a quick test, see the Zonite method following this discussion; for a more exact test use the procedure given in conducting a break-point test, dosing with 5 p.p.m. chlorine or more, and allowing a 10-minute contact period before the starch iodide titration.

*Coli-aerogenes group*, regular bacterial examinations should



be made on the plant effluent and on samples collected from key points in the distribution system. For the methods of bacteriological examination consult Chapter 20.

### APPROXIMATE CHLORINE DEMAND— ZONITE METHOD

**Principle.** A drop of Zonite disinfectant (1 per cent sodium hypochlorite, 1 ml. = 10 mg. chlorine) is put into the water sample to provide a dose of about 5 p.p.m. of chlorine. The residual, after 10 minutes, is compared with normal values.

#### **Solutions**

Zonite.

Orthotolidin.

**Procedure.** Add 1 drop of Zonite to 100 ml. of water sample in a 4-oz. bottle; mix and set aside for 10 minutes. Add 5 ml. of orthotolidin solution and mix.

A deep yellow to orange color should develop in less than a minute, since the chlorine demand is ordinarily about 1 p.p.m. If no more than a faint yellow forms, pollution is indicated.

## CHAPTER 20

### WATER BACTERIOLOGY

**Characteristics of Bacteria.** Bacteria are the simplest form of plant life; they consist of only a single cell. As their length ranges between about 0.0004 to 0.0015 of an inch, they are visible only through a microscope. Bacteria as a class are smaller than an ant to the same degree that an ant is smaller than a human. Despite their minute size, bacteria are important in the economy of nature both constructively, as in the cases of organisms that fertilize soil, ferment liquor, ripen cheese, decompose sewage and waste; and destructively, as in the cases of disease-producing forms, termed *pathogens*. According to their appearance or shape, bacteria are divided into three groups, namely:

*cocci*, which resemble round balls.

*bacilli*, whose group of rod-shaped cells includes the greatest number of species in the bacteria family.

*vibrio*, whose cell is curved, resembling a sickle.

Bacterial cells grow singly or in certain distinctive arrangements; this characteristic is useful for purposes of identification. Many species grow to form large masses, called *colonies*, most of which are visible without magnification. In naming bacteria, the genus is stated first, and then the species.

Under favorable circumstances, reproduction occurs about every 20 minutes, but this rapid rate drops eventually, because of overcrowding which reduces the availability of food material and permits the toxic action of waste products. When their surroundings are unfavorable, many bacteria can assume a resistant structure and remain dormant for prolonged periods.

Such formations are termed *spores*; their presence is useful in identification of various species. Some bacteria remain stationary in their suspending liquid except as moved by currents; other species, termed *motile*, move about by means of rudimentary paddles known as flagella. Bacterial cells may be stained with dyes, the tendency to absorb a particular stain varying with the species and thus aiding identification. Spores resist ordinary staining methods.

The growth of bacteria on artificial culture media provides a laboratory means for determining the number and kinds of organisms in water samples. Ordinarily, bacterial media furnish favorable food material and pH condition for promoting cell multiplication. For identification purposes, selective media are used which favor growth of the forms searched for but inhibit the growth of other organisms. Solid media hold each original bacterial cell stationary so that by successive reproduction a separate colony, visible directly or with a reading glass, is formed corresponding to each bacterium originally present. Liquid media are used for their selective action and to enrich the bacteria content of a sample, so organisms may be removed for further culture or examination. An incubation temperature of 37°C. (98°F.) is selected because pathogenic bacteria and intestinal forms grow best at body temperature. Sterile material and procedure must be used to avoid contamination of samples and culture with foreign organisms which are everywhere present. *Aerobic* bacteria require oxygen for respiration; *anaerobes* grow in the absence of dissolved oxygen by their ability to decompose complex oxygen-bearing compounds.

**Bacteria in Pure Natural Water.** Truly sterile water is rarely found in nature; even deep wells and springs may contain a few native bacteria. Surface water always contains a variety of types from soil wash. These normal organisms do not cause disease. They grow best at the temperature of the water in which they exist.

Cocci occur commonly, particularly the pigmented species. Colored bacilli are also widely distributed. In streams receiving considerable surface drainage, normal soil bacteria of the aerobic spore-forming groups, such as *Bacillus subtilis*, or the hay bacteria, are always present. Some of these ferment lactose and thus cause false presumptive tests for coliform organisms. More complicated sheathed forms belonging to the class of so-called "higher-bacteria" frequently found in deep wells are *Crenothrix*, an iron-digesting bacteria, and *Beggiotoa*, a sulfur bacteria.

**Bacteria of Impure Water.** An impure water is regarded as one showing evidence of sewage contamination and, therefore, unfit for human consumption because of the possible presence of pathogenic bacteria. The most important organisms indicative of sewage pollution are *Escherichia coli*, *Aerobacter aerogenes*, *Streptococcus pyogenes*, and various members of the proteus group; these are constant inhabitants of the intestines of warm blooded animals. The first two genera and an intermediate subgroup, termed *Citrobacter*, closely related to *Escherichia* but rarely found in the intestinal tract, comprise the members of the so-called "coliform" group of bacteria. *A. aerogenes* is present also in the soil, and some strains of *E. coli* are regarded as not being of fecal origin. Nevertheless, all species in the genera *Escherichia* and *Aerobacter* are included in the coliform group, the test for which at present constitutes the bacterial criterion of purity.

Tests are made for the coliform group as indicator organisms, rather than search for specific pathogenic bacteria for these reasons:

1. Coliform bacteria, being normal intestinal parasites, are present in enormous numbers in sewage, and consequently, significant amounts are found in polluted water. After discharge from the body, the life span of *E. coli* is limited to several weeks; therefore, its presence indicates animal pollution. If fecal contamination can enter the water, infected

excreta carrying pathogenic bacteria may enter by the same route.

2. Test methods for coliform bacteria are relatively simple.

3. Pathogenic bacteria, from discharges of patients, are relatively few in number compared with the coliform content in the water; thus the coliform test usually allows a very high factor of safety.

4. Demonstration of specific pathogens is a specialized undertaking, too involved for the usual water plant laboratory.

*E. coli* is ordinarily regarded as a harmless bacteria, but occasionally it has caused inflammation of the gall bladder and urinary bladder. *A. aerogenes* is not known to be pathogenic. Streptococcus and proteus bacteria are of interest in swimming pool sanitation.

**Water-Borne Diseases.** Pathogenic species which can live in natural water are those of the intestinal diseases; they include the following micro-organisms:

| <u>Organism</u>                  | <u>Disease</u>      |
|----------------------------------|---------------------|
| <i>Eberthella typhosa</i>        | typhoid fever       |
| <i>Salmonella paratyphi</i>      | paratyphoid A       |
| <i>Salmonella schottmuelleri</i> | paratyphoid B       |
| <i>Shigella dysenteriae</i>      | bacillary dysentery |
| <i>Entamoeba histolytica</i>     | amoebic dysentery   |
| <i>Vibrio cholerae</i>           | Asiatic cholera     |

Cholera outbreaks no longer occur in North America. The virus of infantile paralysis has been found in the sewage of communities where this disease was epidemic. *Pasturella, tularensis*, the cause of rabbit fever, has been shown to occur widely in streams of the Northwestern United States. In the tropics, parasites derived from human wastes are excreted by snails in rural water supplies, causing schistosomiasis, a stubborn, intestinal disease.

Aside from these diseases, imperfectly sterilized water supplies have caused a condition termed gastroenteritis, whose most marked symptom is diarrhea. Such diarrheas develop from a few hours to several days after drinking infected water; bacterial tests may fail to disclose pollution. The onset of

typhoid is about 10 days after infection; these outbreaks may follow an earlier gastroenteritis epidemic.

Water-borne epidemics are characterized by a sudden appearance and widespread distribution of cases among the consumers. The water-borne diseases of importance in the United States are gastroenteritis and typhoid fever.

## LABORATORY TESTS

Laboratory training can be obtained with best results by direct instruction from informed individuals or by spending a short apprentice period at a laboratory regularly engaged in water bacteriology.

Two kinds of test are made; one for the total number of bacteria per milliliter of sample and the other for the presence of organisms indicative of sewage pollution, namely, the coli-form group (sometimes referred to as the coli-aerogenes group).

**Sampling.** A wide-mouth glass-stoppered bottle, 4 to 8-ounce capacity, is previously cleaned with soap or washing compound, rinsed, stoppered, its top covered with tin foil, wrapped in kraft paper and sterilized in a dry cabinet at 170°C. (338°F.) for 1½ hours. A dry sterilizer may be made from a gas oven, an oil stove, or simply a metal box in which are placed a couple of 200 watt electric bulbs. Bottles so sterilized should not be unwrapped until the operator is actually ready to collect the water samples.

Finished water is sampled both at the plant and in the distribution system, according to the U.S.P.H.S. frequency schedule based on population, as follows:

| Population | Minimum Number of<br>Samples per Month |
|------------|--|
| 2,500      | 1                                      |
| 10,000     | 7                                      |
| 25,000     | 25                                     |
| 100,000    | 100                                    |
| 1,000,000  | 300                                    |

Steps in sampling are completed in the following order:

1. Select the sampling fixture.

A tap, such as a faucet, petcock or small valve, without leak at the bonnet or stem is preferable. A large valve or nipple is a second choice because of the greater difficulty in sterilizing and less control over the issuing stream. Fire hydrants are poor sampling stations because of the impossibility of sterilizing the long barrel; in such cases, reliance is placed on lengthy flushing. Bacteria find a favorable food supply in the leather parts of the valve and may wash off into the passing water. After rains, an empty fire plug may readily become contaminated through the weep hole.

2. Sterilize the outlet.

Sterilize the nozzle by flaming with an alcohol lamp, blow torch or torch made by tightly twisting a sheet of paper. A cotton wad, held by a twist on the end of a wire and soaked in alcohol, is a handy torch.

3. Flush-out the line.

Draw water for three or four minutes or until it is judged that contents of the line have been completely displaced back to the main, or, until the water shows normal turbidity. When sampling from a deep well, all drop pipe water should be changed.

4. Have the sampling bottle ready.

Unwrap the sterilized bottle and loosen the tin foil about the cap. Do not touch the mouth of the bottle or stopper with fingers, otherwise the sample will show contamination. Handling only the bottom tip of the tin foil, spread it out like an umbrella over the glass stopper.

5. Catch the water sample.

Remove the stopper, holding by the tin foil over the mushroom top, and almost fill the bottle in the stream of water from the tap.

6. Replace the stopper.

Replace the cap and press the tin foil into position again without contaminating accidentally by contact with the fingers.

7. Label the bottle.

The label should state plainly the source of the supply, the exact location sampled, the chlorine residual found at the time of sampling, and the time of day. Note any special conditions which may suggest contamination, so that in the laboratory proper dilutions may be made to cover the range of expected bacterial concentration. Information on the label may also be an important aid in interpretation of results.

8. Wrap the sample again in the kraft paper jacket if this has not been destroyed.

9. Dispatch the sample in an iced container to reach the laboratory as soon as possible.

Impure water should be tested within six hours; relatively pure water within twelve hours. Miscellaneous bacteria are found not to multiply below 45° to 50°F.; coliform bacteria begin to die off. Consequently, samples should be examined early. In the presence of residual chlorine, sterilization continues in the bottle leading to erroneously low results, especially during long transit. To prevent this action, a crystal of sodium thiosulfate should be placed in the bottle before sterilization to act as a dechlor on the sample.

Samples from open reservoirs are scooped up from about one-foot depth by a quick pass while holding the bottle with mouth forward. This is to prevent water in contact with the hand from flowing into the bottle. Avoid locations where scum or dust floats on the surface.

Bucket-drawn shallow wells are sampled by first discarding several bucketfuls of water in order to flush the container, and finally scooping out a sample with bottle mouth forward somewhat as in an open reservoir.

**Laboratory Materials.** Agars and broths for the growth of bacteria from water samples are most conveniently prepared by dissolving proper amounts of dehydrated media directly in hot distilled water, then placing required portions into test tubes or fermentation tubes, plugging them with non-absorbent cotton, and sterilizing in an autoclave or pressure cooker at



15 psi. steam pressure (248°F.) for a quarter of an hour. Air is released from the autoclave through a petcock which is closed when steam begins to escape. After completing the sterilization, the steam is very slowly released so that liquids do not boil up to the cotton plug. Flasks containing measured amounts of tap water (not distilled water) for dilution are sterilized in the same manner. Petri dishes and transfer pipettes, placed in a metal box, are sterilized in the dry cabinet.

After inoculating the media with water sample, the culture is placed in an incubator held at 37°C. (98°F.), as pathogenic and parasitic body forms thrive best at this temperature. Soil bacteria, on the other hand, are grown in a 20°C. incubator. Incubators may be purchased from laboratory supply houses or may be made by lining a cabinet with fiber board, supplying heat by a strip type of electric heater, and controlling the temperature by means of a thermostat, such as is used for chicken hovers.

## TOTAL COUNT

The total count reveals the number per milliliter of those bacteria present that are able to grow on the media used at the temperature of incubation. Ordinarily, nutrient agar is used and a count of the colonies made after 24 hours at 37°C. When soil forms also are of interest, a culture is similarly made on nutrient gelatin and inoculated for 48 hours at 20°C.

No definite quality standards are based on the total count, except the broad specification that it shall be low. In a water plant, the numerical nature of this test furnishes a basis for calculating the efficiency of bacterial removal by comparing the total count in the raw water and in the effluent. Sudden changes in total count of the finished water may warn that some weakness has developed in treatment.

**Medium.** Stir 23 g. of Bacto-Nutrient agar in 1 l. of cold distilled water; boil for a minute or so; distribute 10-ml. por-

tions to test tubes; insert a cotton plug and sterilize for 15 minutes after pressure reaches 15 psi.

### **Method**

1. Place a tube of nutrient agar in cold water and heat until melted.

2. Allow agar to cool to slightly above its solidification temperature (42°C.). A tube held against the inner surface of the forearm should not cause discomfort.

3. Shake the water sample bottle 25 times.

4. Withdraw a 1-ml. portion of the sample by means of a sterile pipette, and transfer it to a sterile petri dish. Move the cover of the dish aside only slightly to insert the pipette.

5. Place a 1-ml. portion of the sample in a dilution bottle containing 9 or 99-ml. of tap water for 1:10 and 1:100 dilutions, respectively. Ordinarily, well water and plant effluent should not require dilution. This step is taken only when testing raw surface water or when contamination is suspected.

6. Transfer 1 ml. of the dilutions to petri dishes by means of sterile pipettes.

7. Pour the contents of a lukewarm agar tube into each seeded petri dish.

First flame the plug and top edge of the test tube so that no contamination will be picked up during pouring. Do not move the cover of the dish any further than necessary so that airborne bacteria are excluded. Also pour out a "blank" in a plate without water to check the sterility of the agar.

8. Mix the agar and water in the petri dish by gently swirling the dish on the table. Allow to stand long enough to solidify.

9. Incubate agar plates, bottoms up, at 37°C. for 24 hours. By inverting, moisture collected on the cover does not drain back over the cultures and ruin them.

10. Remove plates and count colonies, using a reading glass if necessary, and record the numbers so found as the total bacterial count per milliliter. On dilutions, apply the proper

dilution factor. If more than 300 colonies occupy a plate, counts are too low because of overcrowding; such plates are disregarded when averaging figures for the result. Only when the colonies on a dilution number between 30 and 300 is it included quantitatively.

## COLIFORM BACTERIA

**Principle.** Since the presence of the coli-aerogenes group is regarded as indicating sewage pollution, this test is the most important one in water bacteriology. By definition, these bacteria include all organisms that ferment the sugar lactose with production of gas; grow aerobically in characteristic colonies on certain solid media; fail to absorb the so-called Gram stain (are Gram-negative) and lack the power of spore formation.

The first step in demonstrating the possible presence of this group consists in incubating the sample in a liquid broth containing various nutrients and lactose. As lactose can be fermented only by relatively few bacteria, the presence of any gas in the small inverted vial inside the fermentation tube indicates that members of the coliform group are possibly present. This step is known as the *presumptive test*; if negative, no coli-aerogenes bacteria are in the culture; if positive, their presence is probable.

A few other lactose-splitting forms of minor sanitary significance must be excluded. The simplest method for ruling out false presumptive tests consists in inoculating a small portion of the fermented lactose broth into a selective medium which permits the growth of coli-aerogenes members but inhibits other lactose-splitters, mainly certain spore formers. Brilliant green bile broth (2% bile) is such a medium; it is inoculated with a loopful of fermented lactose broth from the presumptive test and observed for gas formation. Addition of this step constitutes the so-called *confirmed test*.

Observation of the fermented presumptive tube is helpful.

Coliform organisms develop quickly; produce gas in 18 hours; make the broth cloudy, but with little sediment or odor. On the other hand, lactose-fermenting anaerobes develop slowly, usually not gassing until 36 hours when the broth works like wine, forming sediment and producing a rancid odor.

Other and more complete methods of confirmation are sometimes used, and differential tests have been developed to distinguish between the coli and aerogenes members of the coliform group, and even to indicate the source of *E. coli* as from warm-blooded or cold-blooded animals; or from non-fecal origin. However, the primary presumptive test followed by the confirmatory brilliant green bile broth will suffice for the usual water plant laboratory. For the longer procedure, the reader may consult *Standard Methods of Water Analysis*.

## PRESUMPTIVE TEST—LACTOSE BROTH

**Medium.** Dissolve 13 g. of Bacto-Lactose broth in 1,000 ml. of distilled water; distribute 30-ml. portions in fermentation tubes (test tubes with a small inverted vial inside); insert cotton plugs and sterilize in an autoclave at 15 psi. for 15 minutes.

### Method

1. Shake water sample 25 times.

2(a). In the case of plant effluents and ground-water from protected wells, transfer 10-ml. portions, by means of a sterile pipette, to each of five fermentation tubes. Also transfer a 1-ml. portion to a fermentation tube in the same manner. Fermentation tubes that contain 1 ml. of sample or less may be prepared in smaller test tubes containing 10 ml. of broth.

Prepare a dilution by adding 1 ml. of sample to 9 ml. of sterile tap water, and with a fresh pipette add 1 ml. to a fermentation tube. The various volumes planted, or *inocula*, therefore, consist of five 10-ml., one 1-ml., and one 0.1-ml. portions.

2(b). In the case of raw waters and other samples judged

to be contaminated, plant a 10-ml. portion in one fermentation tube; and a 1-ml. portion in another.

Prepare dilutions by pipetting 1-ml. portions to flasks containing 9 ml. and 99 ml. respectively of sterile tap water. With fresh sterile pipettes transfer a single 1-ml. portion from each of the dilution flasks to fermentation tubes. This procedure yields a series of inoculation volumes of 10 ml., 1 ml., 0.1 ml. and 0.01 ml., which spread should be wide enough to show a negative result in the smaller portions for all but very heavily contaminated samples.

3. Incubate seeded fermentation tubes at 37°C. for 24 hours.

4. Observe for gas formation. Any tube with over 10% of the inverted vial volume containing gas is regarded as positive; that is, it gives a *positive presumptive* test for coliform bacteria. This test should be confirmed by the next test.

Tubes without gas formation should be returned to the incubator for a second 24 hours, then observed again. A vial showing gas in any quantity, however small, is reported as a *doubtful presumptive*, which also should be confirmed. When no gas is formed, the test is reported as *negative*.

Instead of planting five 10-ml. portions, a closer count can be obtained on finished waters when using five 100-ml. portions. This larger volume necessarily requires use of more media and occupies larger space in the incubator.

*Short Cut Presumptive Test.* The short cut described presently combines sampling with inoculation, thus simplifying and accelerating the test. It is useful particularly for laboratories having only limited facilities and personnel. Whenever a large number of samples must be collected or during emergencies, as in air raids, this method may be used to give results in the shortest time and with the least effort. No dechlorination is required as the organic material in the media strips the sample of any residual chlorine.

This method consists simply in placing a small volume of concentrated lactose broth in the sample bottle, enclosing a fer-

mentation vial with closed end up, and then sterilizing the assembly in an autoclave. After drawing a sample in the usual manner, the bottle is rotated to effect uniform mixing and then inverted to fill the gas vial with liquid. The sample is then incubated. The procedure is detailed below:

1. Make a mark with a wax pencil or file at the 100-ml. level on a four-ounce bacterial sample bottle.
2. Place 0.65 g. of Bacto-Lactose broth powder in the bottle. This weight of material may be measured out in a small scoop.
3. Add about 2 ml. of distilled water to dissolve the medium. This is necessary to prevent darkening, and consequent decomposition of the medium during sterilization.
4. Place a fermentation vial, opening downward, into the bottle.
5. Place tin foil over the stopper, wrap in kraft paper, and sterilize in the autoclave at 15 psi. for 15 minutes.
6. Sterilize the tap preparatory to taking a sample.
7. Fill sample bottle with water to the 100-ml. mark.
8. Replace stopper, press tin foil back in place, and twirl the bottle to dissolve the medium and distribute it uniformly.
9. Invert the bottle to displace the air from the fermentation vial and cause it to be occupied with liquid.
10. Incubate at 37°C. or place in a warm spot.
11. Observe for gas formation at the end of 18, 24, and 48 hours.
12. Run a confirmatory test as soon as gas forms, if one is needed.

The steps outlined above are most conveniently performed in a special bacteriological sample bottle, termed a *colimeter*, in which auxiliary reservoirs and inverted vials are fused to provide subdivision of the sample internally into different sized portions. A confirmatory test with brilliant green bile broth is started automatically in a small looped tubeful of this material inserted into the reservoir shortly after sampling.

## CONFIRMED TEST—BRILLIANT GREEN BILE LACTOSE BROTH

(B.G.B. broth, 2%)

**Medium.** Dissolve 40 g. Bacto-Brilliant Green Bile, 2%, in 1,000 ml. of distilled water; distribute 10-ml. portions in fermentation tubes, plug with cotton, and autoclave at 15 psi. for 15 minutes.

### Method

1. Sterilize a platinum wire loop by holding in a flame until red hot.
  2. Dip the loop into the lactose broth tube giving a positive or doubtful presumptive test.
  3. With the above loopful of material, inoculate the brilliant green bile broth tube.
  4. Incubate the brilliant green bile tube at 37° for 24 hours.
  5. Observe for gas formation at the end of 12 and 24 hours.
- Any show of gas is regarded as a confirmed test for the coli-aerogenes group. Record results and report from Table 17 or 18 the most probable number of coli-aerogenes organisms per 100 ml. of sample.

**Most Probable Number.** A disadvantage of the broth method of culturing bacteria is that, unlike solid media, there is no isolation of the originally individual cells into colonies which could be counted separately.

For coliform bacteria in treated water samples, an enrichment method, such as with the presumptive lactose broth, is necessary so that growth of weak strains will be encouraged. In order to give a numerical value to various combinations of positive and negative tubes in a set of inoculations from a single sample, a method based on the theory of probability is used. This method gives the so-called *most probable number* (MPN) of coliform bacteria per 100 ml. of water. Strictly, the most probable number should be expressed only for tubes carried

through the confirmed test, but frequently this enumeration is also applied to the results of the presumptive test. Tables 17 and 18 give MPN values for possible results with the two sets of tubes mentioned in the preceding procedures.

TABLE 17  
Most Probable Number of Coliform Bacteria Per 100 ml.

| INOCULATIONS  |       |         |                    |
|---|-------|---------|--------------------|
| <i>Five 10-ml., One 1-ml., and One 0.1-ml. Portions</i> |       |         |                    |
| Number of Positive Tubes                                |       |         |                    |
| 10-ml.  | 1-ml. | 0.1-ml. | MPN per<br>100 ml. |
| 0   | 0     | 0       | 0.0                |
|   |       | 1       | 2.0                |
|   | 1     | 0       | 2.0                |
|   |       | 1       | 4.0                |
| 1   | 0     | 0       | 2.2                |
|   |       | 1       | 4.4                |
|   | 1     | 0       | 4.4                |
|   |       | 1       | 6.7                |
| 2   | 0     | 0       | 5.0                |
|   |       | 1       | 7.6                |
|   | 1     | 0       | 7.6                |
|   |       | 1       | 10                 |
| 3   | 0     | 0       | 8.8                |
|   |       | 1       | 12                 |
|   | 1     | 0       | 12                 |
|   |       | 1       | 16                 |
| 4   | 0     | 0       | 15                 |
|   |       | 1       | 20                 |
|   | 1     | 0       | 21                 |
|   |       | 1       | 27                 |
| 5   | 0     | 0       | 38                 |
|   |       | 1       | 96                 |
|   | 1     | 0       | 240                |
|   |       | 1       | Indeterminate      |



*Example.* A combination of two 10-ml. tubes positive with the 1-ml. and 0.1-ml. tubes negative, corresponds to an MPN of 5.0 coliform bacteria per 100 ml. of sample.

TABLE 18

Most Probable Number of Coliform Bacteria Per 100 ml.

## INOCULATIONS

*One 10-ml., One 1-ml., One 0.1-ml. and One 0.01-ml. Portions*  
Result of Test

| 10-ml. | 1-ml. | 0.1-ml. | 0.01-ml. | MPN per<br>100 ml. |
|--------|-------|---------|----------|--------------------|
|        |       | —       | —        | 0.0                |
|        |       | —       | +        | 9.0                |
|        | —     | —       | —        | 9.0                |
|        | —     | +       | +        | 18                 |
| —      |       | —       | —        | 9.4                |
|        |       | —       | +        | 19                 |
|        | +     | —       | —        | 19                 |
|        | +     | +       | +        | 29                 |
|        |       | —       | —        | 23                 |
|        |       | —       | +        | 90                 |
|        | —     | —       | —        | 94                 |
|        |       | +       | +        | 190                |
| +      |       | —       | —        | 230                |
|        | +     | —       | +        | 950                |
|        |       | +       | —        | 2,400              |
|        |       | +       | +        | Indeterminate      |

*Example.* A result showing the 10-ml. tube positive, the 1-ml. tube positive, the 0.1-ml. and 0.01-ml. tubes both negative, is equivalent to a MPN of 230 coliform organisms per 100 ml. of sample.

**Interpretation and Standards.** The bare results of a single laboratory test may not be significant unless considered in the light of a sanitary examination of the source by a qualified indi-

vidual. No conclusion should be drawn without such knowledge of the source. So far as a descriptive classification of a usually reliable potable water can be made from a single sample, the following schedule is sometimes used.

| <u>No. of 10-ml. Portions<br/>Showing Gas out of 5 Tubes</u> | <u>Designation</u>   |
|--|----------------------|
| 0  | satisfactory         |
| 1  | slight contamination |
| 2  | contamination        |
| 3 or more  | heavy contamination  |

The U. S. Public Health Service standards for potable water allow not more than 10% of the 10-ml. portions planted in a month to be positive (confirmed test). This is equivalent to an average MPN of 1.05 coliform organisms per 100 ml. These standards also limit the frequency of tests showing heavy contamination by specifying that 3 or more of the 10-ml. tubes in a set may not be positive in more than 5% of the samples collected in a monthly period. If less than 20 samples are taken per month, this degree of contamination can show no more than once. By this means the MPN may not exceed 8.8 per 100 ml. more than once in 20 samples. This frequency is about 5 times more liberal than that expected from chance variations in a water averaging 1.05 MPN per 100 ml.

If 100-ml. portions are planted, not more than 60% of those examined in a month may be positive. All 5 portions from a single sample may test positive in not more than 20% of the month's samples; should less than 5 samples be examined, this result is permissible but once.

*Further Tests.* Some further description of the characteristics of the coli-aerogenes group on other media is desirable.

On Endo's agar, which contains basic fuchsin dye and sodium sulfite, *E. coli* forms small dark-red flat colonies with a greenish metallic sheen; *A. aerogenes* forms larger convex "pearl button" colonies without metallic sheen. On Eosin Methylene Blue (E.M.B.) agar, *E. coli* forms small dark

colonies with greenish luster; *A. aerogenes* colonies are larger convex masses with a depressed center. Spore-bearing organisms do not grow on E.M.B. agar.

In the complete test for coliform members, the E.M.B. agar is used to confirm the presumptive gas tubes and a typical colony fished off for streaking on an agar surface to furnish material for microscopic examination, namely the Gram stain and motility (movement) test.

Interfering spore formers which might live in union (*symbiosis*) with coliform bacteria are eliminated by transferring colonies from E.M.B. agar to formate ricinoleate broth. This inhibits sporulating organisms, and the enriched coliform growth is again streaked on E.M.B. agar.

Other selective broths sometimes used in the confirmation test are: crystal violet lactose broth; formate ricinoleate broth, and fuchsin lactose broth.

On appropriate media the *E. coli* members of the coliaerogenes group produce indol, turn methyl red to its acid color, but do not give the Voges-Proskauer reaction, nor utilize citrates. Its "Imvic" formula (name suggested by first letter in names of tests) is + + - -. For *A. aerogenes* members the formula becomes - - + +. Other means for differentiation include use of rare sugars, such as celluliose, and temperature selection for incubation.

Pathogenic water-borne bacteria may be grown in special agars after enrichment first in dextrose broth. On bismuth sulfite agar, *Eberthella typhosa* grows luxuriantly into characteristic black colonies, while the coliform group and Gram-positive bacteria are inhibited. Salmonella organisms (Paratyphoid A and B) also yield characteristic colonies on this medium. S S (Shigella Salmonella) agar gives maximum inhibition to coliform members with minimum restriction of Gram-negative intestinal pathogens. In powdered Selenite F, *Eberthella typhosa* outgrows other coliform types thus enabling its use for the isolation of this organism from food products.

Favorable growth of *Shigella dysenteriae*, *Salmonella paratyphi*, *Salmonella schottmuelleri* and *Eberthella typhosa* is obtained on desoxycholate agar.

Strictly speaking, a negative test for the coliform group, as usually performed, does not always prove freedom from intestinal pathogens in water due to the fact that the groups causing typhoid, paratyphoid, and dysentery do not ferment lactose. Below pH 7.0, typhoid bacteria are consistently more resistant to free chlorine than are *E. coli*; in the pH interval 7.0 to 8.5 their resistance is about the same; and above pH 8.5, *E. coli* is usually more resistant. With chloramine, their relative sensitivities are approximately equal.

Under conditions, even a non-confirming positive presumptive test may actually contain coliform organisms that have been repressed (*antibiosis*) by other bacteria, such as streptococci, whose waste products may be detrimental to the colon types. At present, the trend in water bacteriology is toward the development of more selective culture media so that after initial enrichment, the various undesirable species may be quickly grown and recognized.

## SECTION 6. MISCELLANEOUS

### CHAPTER 21

## OPERATION DURING EMERGENCIES

EMERGENCIES may be caused by floods, storms and air raids. In any event the water department should aim to maintain pressure in the distribution system, and where equipment or pipe lines are damaged, to make needed repairs promptly and proceed with emergency disinfection until all danger from bacterial pollution is past.

**Floods.** Wells, ground-water reservoirs, and high-lift pumps should always be located at a site above the highest known water level ever observed in their locality, if this precaution is possible. When a flood threatens to cover a well, the unit should be run continuously to fill the elevated tank and ground storage. Then the motor shaft should be uncoupled, the bolts holding the motor frame to the bed plate loosened, and the motor blocked high enough in the air to be out of reach of the water. The breather pipe should be plugged. Every effort should be made to keep the flood water from entering and contaminating the well. A ring levee of clay mud and sand bags will successfully hold back 5 ft. of water if built wide enough. If this protection can be placed in time, the well may operate throughout the disaster. If flood waters enter a well, a protracted course of chlorination is generally required to reestablish safe bacterial quality. Well chlorination procedure is described in Chapter 3. If any question of contamination exists, the consumers should be notified to boil their potable water until

further notice. Flooded motors are reconditioned by heating, such as in an infra-red lamp cabinet or immersing in hot paraffin. New motors may sometimes be dried with a blow torch if handled by an experienced electrician. Care is needed to avoid burning the insulation.

Flooding of ground storage reservoirs may be resisted by a levee of sand bags. A high level of water on the outside always allows entry through cracks if the structure is not absolutely watertight. A sump pump should be installed in back of the sand bags to remove the leakage. Contents of the reservoir should be chlorinated above 0.2 p.p.m. orthotolidin residual as a precautionary measure, pending completion of bacterial tests.

At the pumping station, the openings should be blocked to within a few feet of the top by sand bags. If the walls of the structure are not of waterproof masonry or concrete, they should be terraced outside and supported inside by sand bags. Water supplied to town should be chlorinated at the pump suction to give not less than 0.2 p.p.m. chlorine residual. A still higher residual chlorine is preferable.

When not in use, sand bags should be emptied, washed clean of soil, dried, and stored. Their life is prolonged, full or empty, by treatment with copper naphthenate.

At plants treating surface water, the motor on the intake pump may become submerged. In this event, raw water may be furnished through a hose line from a pump on a boat or barge. Flooding of buildings is resisted by sand bagging and installing extra sump pumps. The clear water well and reservoir are vulnerable spots and may be contaminated either by flooding or by entry of ground water under unusually high head through cracks. For this reason, the customary chlorine dose should be increased to satisfy any unusual chlorine demand and to raise the residual as a further margin of safety.

**Storms.** Damage by storms includes damage to buildings, overhead wiring, electrical equipment, and broken services. If the station is substantially built, only minor damage will be

suffered. When roofs begin to leak, a make-shift canopy should be thrown over switch-boards and motors. Elevated tanks seldom show damage. Overhead wiring may be blown down; this should be repaired immediately if possible. High-voltage lines should never be strung close to a coagulating reservoir or other tank that requires flushing or washing down by means of a hose stream, as a stray play of the hose may cause an attendant to be electrocuted. Gasoline driven or Diesel stand-by units should tide pumping through the emergency. An ample supply of fuel should always be kept in storage, and the operation of auxiliary power units checked weekly. Some plants burn an oil lantern routinely at night as a guarantee against total darkness. A sufficient number of flashlights with live batteries should be on hand for operators and aides.

Broken services at collapsed buildings are the most serious effect of a severe storm; water is wasted during the time required to close the valves in order to isolate the break. Curb cocks are usually covered by wreckage so as to be inaccessible. Pump or tank pressure should be maintained, since each broken service may allow back-siphonage from the pool surrounding the break if the pressure fails. As each section where leaks are found is isolated, some back-siphonage will reach back into the main, but for a limited length only. Before resumption of normal service, these sections should be chlorinated by the same procedure as is used for disinfecting newly laid pipe-lines. If there develops any possibility of general contamination in the system, a 0.2-p.p.m. chlorine residual should be maintained as a measure of safety. In areas deprived of their normal water supply, a tank wagon should distribute safe water to consumers' containers.

**Air Raids.** A direct hit by a high-explosive bomb on the water plant is unlikely, according to British experience, but an air raid will cause numerous ruptured mains. High-explosive bombs shatter mains at the point of explosion, or crater, and crack pipes a few lengths away through shock. Operation of a

water system in war time requires several lines of precautionary preparations so that damages may be minimized and repairs instituted promptly.

## WAR TIME OPERATIONS

Various aspects of war time protection are presented here for the purpose of preparedness in the future. As a next war may not allow breathing space for organization of a complex protective system before striking within continental limits, operators should never lose consciousness of the value of civilian defense measures. Nothing paralyzes industry and disrupts community morale so completely as does destruction of the public water system. Tactical operations against water supplies has been a military stratagem dating from the Medes' capture of Hamaden, 626 B.C., to the fall of Hong Kong and Singapore in World War II. Aspects of war time operation of importance to water supplies are: Protection against sabotage, preparation for air raids and robot bombs, protective instructions to consumers, procedure during and following air attack and other miscellaneous problems arising from total warfare. During the course of a war certain civilian matters assume prominence such as: varying degrees of blackout, selective service, manpower problems, rationing, priorities, alternate materials, post-war planning and execution. A lesson indelibly learned from World War II is that the water system, in all its departments, should be thoroughly modern, wholly adequate, fully stocked with spare parts, and that extension, maintenance and repair jobs should be promptly attended to.

**Sabotage Protection.** Saboteurs are interested mainly in disabling war industries and utilities serving war plants, military camps, and shipping. Attempts to cripple water supplies in areas without important connection with the war effort might be made in cases where the risk of detection is slight and the effect on public morale damaging.



The following rules should be considered in planning anti-sabotage defense:

1. Avoid casual labor from transients. The plant should be manned by a trustworthy staff of loyal men well known in the community. Whenever extra labor is needed only men with known background should be employed.

2. Visiting to the plant should be controlled. The degree of restrictions upon visiting will vary from strict no-admittance orders to liberal allowances for plant visits from school classes and interested citizens of high standing. Reservoir and grounds should be closed to public usage. In no cases should strangers be allowed to roam unattended through the plant. In a large plant, visitors should be required to secure a pass from the main office before being admitted. No packages should be carried by visitors into the plant. Deliveries should be received outside of the plant structures. Automobiles should be required to park some distance away. Oil and grease cups should be guarded against tampering. No photography should be permitted.

3. Keep reservoir latches, well house doors, back doors, and similar points locked. A hasp and padlock should be placed on ground storage reservoir hatches. If the reservoir has a central screened ventilator, this structure should be made tamperproof. The ladder to the elevated tank should have the bottom section removed and a locked barricade placed on the remaining lower rungs. If the breather pipe on the well terminates in the open, a guard shield should be welded on it in such a way that it becomes impossible for a saboteur to contaminate the well through this means. The check valve should be located within the well house or its cover locked in place to prevent tampering. The back door of the water plant should be locked, so that all entrance must be through the front door; in this way prowlers are less liable to escape detection.

4. A high fence of the cyclone type with barbed-wire top, should be provided to protect the plant. Whereas fences may be vaulted or tunneled, they present an extra obstacle to the en-

trance of saboteurs. In remote sections, the fence may be charged intermittently and an indicating instrument placed where it can be watched to show if the fence has been cut or grounded. Out in the distribution system where fencing is impossible, the valve box covers should be too massive for lifting or they should be hidden by sodding them over.

5. Arrange some type of watchman service, such as best fits the situation. Uniformed guards, provided with elevated shelters, are used in large plants. Watchmen armed with rifles are stationed at isolated vulnerable points, such as intake structures. An interalarm system, by phone, electric bell, radio, or other device is used for reporting periodically. Protection is also afforded by attention from neighbors, by having the plant on a regular police beat, or, by a watchdog, kept behind the plant fence.

6. Provide protective lighting. Exterior lighting should cause glare in the eyes of a trespasser and should illuminate shadowy spots which might serve as hideouts. An independent light source, such as wet batteries or a small portable gasoline driven generator, should be on hand in event of power failure.

7. Avoid certain publicity. Incidents should not be generally discussed nor reports circulated. Rumors should be investigated and proved to be unfounded, as they usually are. Plants serving military camps and war industries should not release records or information on water consumption, as these facts are almost equivalent to figures on military strength and production. Such plants should keep their monthly pumpage reports private until after the war.

8. Laboratory examinations should be increased where advisable. Bacterial tests for coliform organisms should be made according to the frequency schedule given in the U. S. Public Health Standards, at least. Where large or important war establishments are supplied, samples should be taken regularly from its service lines in order to catch the first indications

of pollution, since a water-borne epidemic at a war plant would seriously impede military activities.

Ordinary laboratory tests may be used, in most cases as non-specific indicators of water safety from chemical contaminants. Unusual taste, odor, color and turbidity should be regarded as suspicious. Four common chemical tests are useful, namely pH, alkalinity, oxygen consumed and chlorine demand. Methods for the determination of these quantities are given in Chapter 19. Any sudden, unexplainable increase in any of these values is a suspicious sign. Any unexpected change in the rate of chlorine residual dissipation should be investigated. For supplies without ammoniation, para-aminodimethylaniline or the flash orthotolidin test will indicate changes in free chlorine concentration. Values of oxygen consumed, and chlorine demand 5 p.p.m. above normal are danger signs. Specific tests are available for potent poisons but application of special toxicological procedures are too involved for most plants. Further information is available through the Office of Civilian Defense as needed. Whenever suspicious material is tested, a liberal portion should be set aside for further tests or for transmittal to a Chemical Warfare Service, or Department of Health laboratory.

A biological indicator for poisons consists of the use of fish bowls or tanks stocked with such species as black bass, *gambusia affinis* (top minnows), trout or goldfish. Plankton, such as *daphnia*, also have been suggested. Tanks are placed at the water plant, at critical locations in the distribution system, and on services at war industries. These collections should be protected from sudden temperature changes, should be kept aerated, and the fish properly fed. Duplicate tanks are advisable so that any obscure fish epidemic in any one tank will not cause needless alarm.

**Preparation for Air Raids.** Only by providing remedial measures in advance can a water system minimize the destructive effect of high-explosive bombs. As much as possible, a

full stock of material should always be on hand. Reliance may be placed upon the mutual aid system, through the zone co-ordinator, to supply needed material from near-by communities. The following rules should be considered:

1. Acquire spares and emergency repair material so far as possible, on hand and within reach through mutual aid.

Stocks of spares during war are limited by War Production Board orders, and in many cases by slow deliveries. Aside from the inventory on hand, other utilities in neighboring towns must be depended on to furnish necessary materials after a raid. Inventories of materials in all towns in a zone should be filed with the zone co-ordinator so that, in a necessity, they might be dispatched without delay.

Reserve supplies should be stored at decentralized stations, as scattered stocks are not liable to be destroyed completely nor made inaccessible by wreckage of roads.

Portable chlorinators with independent gasoline drives, supplies of chlorine, tool trailers, and quickly installed repair fittings should be readily available. Milk trucks, oil trucks, and street flushers should be inventoried and committed for emergency use to stricken areas.

2. Recruit and instruct auxiliary crews.

During a raid more incidents occur than can be attended to by the normal gate and repair crew. Extra workers should be procured from the clerical and non-operating personnel of the department. Plumbers and contractors' forces are probably the best outside sources of emergency manpower. Additional requirements should be satisfied by volunteers obtained through the civilian defense organization. Extra personnel should be expanded about leaders who are members of the regular organization; the emergency force generally trebles the normal crew. All auxiliary workmen should be given adequate training along the lines of their intended duties. Sufficient rehearsals of plant and repair operations under blackout conditions should be staged to ensure proficiency of the repair gangs and ability to

assemble and work under adverse circumstances. All men should be instructed in first aid for injuries and in self aid for protection against gas attack. They should realize the importance of promptly removing clothing wet with poison-gas liquids and washing off the skin with liberal amounts of soap and water.

3. Provide for duplication of essential services and for inter-connected supplies.

Duplicate sources of power may include the local electrical utility and a stand-by generator at the plant. Arrangement should be made to use police radio, personal messenger, or privately arranged signals in the event of failure of the telephone system.

Auxiliary sources of water should be arranged through plans for inter-connection with acceptable industrial, institutional or other private supplies. Physical connection should ordinarily be deferred until the need actually develops. Such a tie-in should be distinguished from a cross-connection with an unsafe source. Neighboring communities may install a permanent connection or furnish water through hose and fire hydrants. Before an inter-connection is permitted the quality of the auxiliary supply should be assured. Where sanitary inspection and bacterial tests indicate, auxiliary supplies having below 50 coliform bacteria per 100 ml. may be made safe by emergency chlorination. Tank wagons should be engaged to carry water to sections deprived of water.

Static supplies, such as in improvised reservoirs and ditches, should be planned for fire fighting in case the municipal supply should fail.

4. Keep the plant and distribution system in good working condition.

Poor performance of equipment is both annoying and dangerous during an emergency. Pumping and treatment facilities should be kept in first class operating condition. Valves in the distribution system should be inspected regularly and kept

workable. Mains should be clean in order that their full capacity is available for fire extinguishing. The system should be completely mapped, a master set of plans kept in the office and section maps furnished to each repair crew. Foremen should memorize important valve locations, so that no time need be lost in consulting records in an emergency. The location of valves should be referred to several points since a bomb may destroy some of the landmarks.

5. Prepare for operation during blackout.

Entrances should be sandbagged for protection against flying fragments. The cloth of sandbags may be preserved by soaking in a copper naphthenate solution before filling. A gas trap should be provided to allow operation during a gas attack.

Windows should be covered with lightproof shades of some sort so that the full amount of lighting may be used at the station without leaks to the outside. Plywood cover over decorative transoms and under skylights prevent the overlooking of these areas during a blackout, and also prevent damage from flying glass. This item is important because shattering of window panes by percussion is responsible for widespread injuries. Switches to turn off all exterior lighting should be handy. Structures should be painted to be of inconspicuous, dark colors, and a low-visibility type of aluminum paint is used where protection against weathering must be combined with safety. Roofs should blend in with the surrounding terrain. Filter surfaces may be camouflaged by small green canvas rafts. Poorly visible structures are almost impossible to pick out by high altitude bombers, especially when harassed by pursuit planes or high density anti-aircraft fire. Large bodies of water are almost impossible to conceal. Where structures adjoin such water, large rafts may be floated to disguise the tell-tale margin of the shore line near by. Dense smoke from burning oil in pits two feet deep conceals reservoirs against photography. Exterior valves and controls are lighted for blackout operation by means of various luminous.

or phosphorescent, paints. Fire hydrants, so painted, are less liable to traffic collisions. Dummy installations may be planned with the purpose of confusing enemy aviators. When vegetation is imitated, infra-red reflecting paint is used to avoid detection by photography.

Department vehicles should have regulation headlight dimmers and carry civilian defense pennants in order to be allowed on streets and highways during a blackout. Messengers and crews should be supplied with armband insignia or badges to be allowed outside their houses during a raid.

6. Co-operate in the civilian defense organization.

A water works official should be stationed at the local control center to advise with the utility officer on problems affecting the water system.

An inventory of the reserve material on hand should be furnished to the zone co-ordinator so that mutual aid received from and pledged to other communities might be routed advantageously.

**Instructions to Consumers.** All consumers should be made to understand and appreciate the following home precautions, as advised by the Office of Civilian Defense, in advance of an actual air raid.

1. Fill a quart bottle with drinking water for each person in the house in case the water is turned off.

2. Keep faucets shut if the supply fails, so no wastage will occur when service is resumed.

3. Do not fill bathtubs during alarms, thus depleting the supply.

4. Do not attempt to operate valves on broken lines; leave this task for trained emergency crews.

5. Report troubles only through the air-raid warden.

6. If water supply fails, discontinue use of flush toilet to prevent the accumulation of body wastes. Defecate in a kraft paper bag, which is easily disposed of later, or, use a pit privy if available.

7. Boil cooking and drinking water for 5 minutes during the first 24 hours after an interrupted service is restored, if so advised by health officials.

8. Do not complain if the water has a slight taste of chlorine. Accept this as a sign of safety.

9. Drink water only from taps and authorized drinking-water carts.

10. Discredit rumors. Do not repeat them.

## PROCEDURE DURING A RAID

**Order of Warnings.** Upon notification by the air-raid-warning district center, which usually embraces several states, of the possibility of an air attack, the preliminary yellow signal is flashed at the local control center and the water works official reports to the control center while gatemen and light-repair crews proceed to their stations. As soon as the district warning center judges the planes will probably pass over a given area, the blue signal is transmitted and full preparations are made for a raid. Emergency repair crews and field crews go to their posts. The red signal or action warning intended for relay to the general public, indicates that the raid may occur at any instant. At the conclusion of the raid, a white all-clear message is sounded. The emergency forces are demobilized and permanent repairs started.

**Line of Local Communications.** The following path of communication is suggested by the Office of Civilian Defense to follow bombings which have damaged the water system:

1. Report of the damage is made to air-raid warden.
2. Air-raid warden reports to the Control Center.
3. Control Center reports the damage to the waterworks.
4. Waterworks dispatches nearest gate crew to close valves, investigate extent of damages, and make minor repairs.
5. Gate crew reports valve closures and extent of damage to the waterworks.



6. Waterworks orders nearest repair crew to place of incident, if needed.

7. Waterworks reports extent of the damage and action taken to Control Center.

8. Repair crew reports completion of work to the waterworks.

9. Waterworks reports completion of work to Control Center.

**Emergency Repairs.** After arrival at an incident, the gate crew closes valves to prevent loss of water through broken mains.

The emergency repair crew plugs the breaks, pumps out the hole, makes temporary connections across the bomb crater for fire fighting, connects auxiliary supplies to the system and chlorinates repaired lines and inter-connected supplies, if required.

Permanent repairs are begun after the raid is over or during daylight.

Quickly installed fittings which may be tightened with a wrench, are useful in making emergency repairs.

Special blanking off plates, fire hose adapters and manifolds are used at broken ends of mains. In this country, Skinner, Dresser, Clow-National mechanical joints and other repair fittings should be stocked to permit rapid pipe assembly across a crater. Simplex sleeves and rubber rings permit quick flexible connections of asbestos cement pipe. Split sleeves are useful in covering short cracks. They may also be used as clamps at gasket pressure joints. An extra valve may be conveniently inserted in a fractured line by making up the span with a stuffing box type of cutting-in sleeve.

As the craters usually contain sewage, it is imperative that drinking and cooking water is boiled for five minutes because chlorination, even in high dosage, is ineffective to kill bacteria contained within protective organic matter. This contamination should be removed so far as possible by flushing and a 50-p.p.m.

chlorine residual maintained in the replaced and polluted sections for 24 hours. The main should then be flushed until the normal residual is reached, bacterial samples taken, and the line released, if the tests are satisfactory. When flushing, contamination should not be allowed to reach other sections of piping beyond the valves. A general high level of chlorine, 0.2 to 0.5 p.p.m. orthotolidin residual, should also be carried in the system as a whole. Chlorine is best injected through a portable chlorinator, reliance on the placing of H.T.H. powder in each length of pipe is a makeshift substitute. H.T.H. solution may be injected into small pipes by means of a stirrup pump. Static supplies subject to contamination, as in reservoirs, should receive a 2.5-p.p.m. chlorine dosage. Further information on chlorination may be found in Chapter 9. The information in Table 19 is helpful in figuring chlorination quantities.

When poison gas has reached the water supply, local authorities should be consulted and samples sent to a Chemical Warfare Service laboratory for identification. Mustard gas, below 500-p.p.m. concentration, may be boiled out. Lewisite decomposes on contact with water to yield arsenical products which are highly toxic; such water must be discarded. Other chemical warfare agents should be handled as advised through health department channels.

TABLE 19

## Emergency Chlorination Quantities

*Amount of Hydrochlorite Required for 50 p.p.m. Dosage in Replaced Mains*

| Diameter<br>of<br>Pipe<br>in. | Ounces per 100 feet                    |                     |
|-------------------------------|--|---------------------|
|                               | HTH,<br>Perchloron,<br>Hoodchlor, etc. | Bleaching<br>Powder |
| 4                             | 0.6                                    | 1.8                 |
| 6                             | 1.4                                    | 4.2                 |
| 8                             | 2.5                                    | 7.5                 |
| 10                            | 3.9                                    | 11.7                |
| 12                            | 5.6                                    | 16.8                |
| 14                            | 7.6                                    | 22.8                |
| 16                            | 10.0                                   | 30.0                |
| 18                            | 12.6                                   | 37.8                |
| 20                            | 15.6                                   | 46.8                |
| 24                            | 22.3                                   | 66.9                |
| 30                            | 35.0                                   | 105                 |
| 36                            | 50.3                                   | 150                 |

Amounts of Sterilizing Agent for Questionable Supplies  
in Tanks and Reservoirs

|  |                           |
|--|---------------------------|
| Desired Dosage   | 2.5 p.p.m.                |
| Ounces of Chemicals, per 1,000 Gallon Capacity:                        |                           |
| Bleaching powder (25% avail. chlorine)                                 | 1½                        |
| HTH  | } (75% avail. chlorine) ½ |
| Perchloron   |                           |
| Hoodchlor, etc.  |                           |
| Sodium hypochlorite (1% solution)                                      | 1 quart                   |
| Sodium thiosulfate for dechlorination,<br>add after 30 minutes contact | ½                         |

Note: A heaping tablespoonful holds approximately  
½ ounce of powder.

## CHAPTER 22

# RECORDS AND OPERATOR POLICY

## RECORDS

THE keeping of proper records constitutes an integral part in the efficient management of a water plant. The prime objects of a set of records are to systematize and improve operation and to furnish information covering past observations and experiences. Aside from these benefits, records may form a basis for plans when expansion of the system is considered, and also furnish valuable defensive evidence whenever unfair criticisms are made of the operators. The extensiveness of a system of records obviously depends on the size and character of a particular plant. Coverage should be adequate. No system is so small that some form of simple record should not be kept. Types of records useful to a plant operator are the following: daily record, diary, monthly summary, and the annual report. Ruled sheets, arranged to simplify entries, should be used for all numerical records. These should be bound or perforated for permanent filing.

**Daily Record.** The daily record sheet should contain all numerical data connected with the plant routine. A typical daily log for a small treatment plant is shown in Figure 48.

In a simple system, consisting of a pumped well and a high lift pump, the record should show the time each pump was turned on or off; from this is obtained the number of hours each unit operates during a day. For cases where the pumps are operated through float-controlled switches, the number of hours of operation is easily counted by placing a self-starting

WATER PURIFICATION PLANT      RIVERSIDE, LOUISIANA      MONTH OF \_\_\_\_\_ 194\_\_

[illegible]

FIGURE 48  
Typical Daily Records for Monthly Report Sheet  
(Courtesy of *Water Works & Sewerage*)

electric clock in each motor circuit; the connection is made through a transformer mounted on the cold side of the motor switch. Some plants may record the reservoir and tank gage readings at certain hours throughout the day or, in manually controlled stations, take the readings when a pump is turned on or off.

Where a master meter is installed on the line to the distribution system, this is read at a certain hour daily. At the same time the kilowatt-hour meter readings, in each pump circuit, are also read. A remarks column, 3 inches wide, and a blank column in which to enter a reference number to events posted in a diary complete the sheet.

In a treatment plant, the daily record embraces all materials and all units; for large plants or complicated treatment, a separate record sheet is usually kept at each station. In most instances, the exact forms best suited to an individual plant can be determined by means of mimeographed trial blanks. Pumpage, reservoir levels and power readings are posted as above. For a surface supply, the record includes the water level read from a staff gage. A chemical record tabulates the weight of each chemical used daily and the dosage in parts per million; the same sheet may include results of laboratory tests on raw water, finished water, and control tests at important steps in the process, such as the effluent from the settling reservoirs. A record of chlorination may be provided on the chemical sheet or on a separate form. These data include the rate setting on the chlorinator, the weight of the chlorine cylinders every morning, the number of pounds used since the last reading, and the orthotolidin residuals in the filter influent, effluent, and at important points in the distribution system.

The filter sheet tabulates separately for each filter the time of cutting in and out of service, the rate setting, the accumulating length of run, the time and length of backwash, amount of wash water used, the final turbidity of the spent washings if taken, the per cent of wash water and the initial and final loss

of head. The loss of head may be read periodically throughout a run. A separate operating record is usually kept for the distribution pumps.

Where bacteriological tests are made, a separate sheet is kept for these results, except when only a single sample of finished water is tested, in which case the findings are reported on the same sheet with the chemical laboratory figures. Plants that use several record sheets should combine the important over-all figures on a daily summary of operations sheet. On all these sheets, a liberal space for "Remarks" column should be allowed. On the main detail sheets, particularly for laboratory tests, an extra blank column should be provided for an occasional series of unexpected data. Many operators prepare a graph to show the day-by-day variation in chemical tests and other values of importance at their plant.

**Diary.** Many miscellaneous incidents that occur constantly in plant operation do not fit into the daily record but are sufficiently important or helpful to be included in a permanent record in diary form. Such information as the following may be entered: occasional numerical data and measurements, maintenance items, replacements and repairs, trouble and various methods tried for correction, complaints from consumers, visits by officials or authorities and their remarks, reports from others such as Department of Health inspections and tests, and similar facts that an operator always appreciates in time of need. These entries may be quickly located if the daily summary sheet contains a key letter or word for cross reference. Instances arise where knowledge of the date of a certain occurrence, even without further detail, is helpful.

**Monthly Report.** The monthly report sheet is usually a tabulated summary of daily data that has been totalled, averaged and scanned for maximum and minimum values throughout the month. In Figure 48 the daily record has been arranged to serve also as a monthly report. A concise statement of important developments may be added with advantage for the

information of officials as well as for later reference. Unit costs for pumping, treating and filtration are usually calculated monthly from figures given in this report.

**Annual Report.** The annual report is modeled along the same plan as the monthly report. It usually contains a compilation of the monthly summaries which in turn are totalled, averaged and marked for maximum and minimum values. Average annual unit costs are included as an important part of this report. A brief résumé of important incidents in plant operation may accompany the above numerical data. Water departments exchange reports with each other so that operators may note the problems and performances in other localities and thus be spurred to best efforts.

In municipalities where monthly or annual reports are not demanded by the local officials, the operator should summarize results periodically for his own information and guidance, and as a basis for future planning.

**Informational Flow Sheet.** In order to have important facts quickly accessible, every plant operator should compile an informational flow sheet that gives essential numerical data directly indicated on simple drawings which show the course of treatment through the various units. For the tanks, such information will include: elevations, length, width, diameter, height, total volume, volume to overflow level, gallons per inch, gallons per foot, time required to fill, retention time, sizes and length of connecting piping and drains, loss of head through unit at various rates; for pumps: gallons per minute, gallons per hour, customary heads, size of motor, volts, amperes, cycles; for dry feed machines: strokes per minute, delivery at various settings. In some cases, calibration curves may be attached to this sheet. Whenever basic measurements are made, they should be recorded on the informational flow sheet.

Name plate data of various pieces of equipment should be collected in some permanent record so that this information is not lost when the unit has weathered or when painted over.



Lists of parts from which to order replacement items should be carefully filed. A well ordered written schedule should systematize the performance of routine maintenance jobs.

## PUBLIC RELATIONS

**Minimum Policy.** By the term public relations is meant the dealings of a water department with its customers, aside from its legal duties and obligations, through which are developed confidence and good will. The sale of water to a community should be considered as an act of merchandising; the product should always be of standard quality and the personnel efficient and courteous in rendering service. The following points are important:

1. Never permit conditions to exist which might interrupt pressure.

Aside from public sensing of some break-down or failure at the pumping station, there are the dangers due to (a) lapse in fire protection and (b) contamination resulting from back-siphonage through faulty fixtures and leaky joints. Always have an ample stock of materials and spare parts on hand.

2. Be certain that the water is always properly treated.

A fair degree of uniformity is expected in the plant effluent. Conditions that permit the development of taste and odors should be under control, or the resultant tastes removed at the plant. Tastes from excess chlorine, or from chlorine combination products should be avoided.

3. Maintain a system of records to serve as evidence of the proper operation of the plant.

4. Keep equipment clean and in good working order.

Good operation is the most important item in good maintenance. Systematize inspection dates and operations for each piece of equipment.

5. Give prompt and efficient attention to complaints.

**Positive Development.** In addition to the expected services

listed above, the water plant operator may build up public pride in his plant and esteem for his management by observing the points below:

1. Provide a water from which any original objectionable characteristic has been removed.

Facilities for iron and manganese removal, color removal, softening, taste and odor control, and corrosion control should be provided where needed. This phase is more frequently a problem of financing than one of water treatment. Exhibition of results from jar tests, or a pilot plant, provides a stronger argument than mere words for the authority or funds to obtain needed equipment. Planning should be done now for post war improvements and extensions.

2. Do not allow pressures to decrease because of corrosion in the mains.

Cleaning of feeders and mains is equivalent in effect to laying additional pipe-lines. Always follow up cleaning of pipes by corrosion-control; otherwise, the rate of corrosion will be accelerated.

3. Make the plant attractive in appearance.

Plant trees and shrubbery on the station grounds, and line borders, fences and walks with gardens. Keep the lawns green and mowed, or, better yet, plant all the available grounds in a victory garden to serve as an example to the community. Paint the buildings, exterior and interior. Keep equipment painted bright and clean. Ornamental brass should be polished; a coat of clear lacquer applied to a polished surface will retain the luster for a long time. Never allow dust or trash to accumulate. Lighting fixtures should be modern and pleasing. Be sure that toilets and dressing rooms are immaculately clean. Neatly arrange tools on a board with a painted space for each item. Correct any unsafe or dangerous structures or equipment. Adequate first aid cabinets, gas masks and fire extinguishers properly placed are generally viewed by visitors as evidence of attentive operation.

4. Never allow a naturally grouchy employee to hold a position requiring contact with the public.

This rule applies particularly to complaint shooters and to cashiers. A pleasant personality should be a requisite for appointees in these and similar positions.

5. Publicize the plant.

Acquaint school children, civic organizations and similar clubs with the virtues and needs of the local system and its product by means of speeches and newspaper articles. Radio and movie films are also employed by large plants. Ordinarily, visiting, with guide service, is encouraged. Many stations post charts and diagrams on their wall to convey messages to visitors. Informative signs on various pieces of equipment aid in comprehension and especially facilitate explanations to large groups. Small scale models and bottled samples are always interesting.

6. Participate in technical organization meetings.

The public is inclined to feel that an operator, active in professional circles, must be one who is competent, aggressive, and abreast of the times.

Misunderstandings with consumers may be largely avoided by handing them a printed booklet containing rules, regulations, and general information when turning on their meters. This pamphlet should instruct consumers in procedures to follow during an accident or an emergency.

## OPERATOR ADVANCEMENT

An operator may usually advance his position by competent attention to his work and by pursuing a policy of self-improvement. The means for self-improvement consist in self-education, training programs, and association membership. For the purpose of breaking-in new men, a planned maintenance program throughout the plant is an effective teaching method.

**Self-Improvement.** Self-education is largely a matter of well planned reading. An alert operator should purchase text-

books covering his type of treatment and equipment, and study these earnestly. A list of helpful books is given in Chapter 23. Most publishers will send out books on approval and allow a 10-day free examination by the prospective purchaser to determine their suitability for his needs. An operator interested in providing vocational ground work should consider studying through a correspondence course. Periodicals provide a wealth of currently valuable information; every plant should subscribe to at least one technical journal. Some manufacturers issue their own trade publication mainly for their advertising value; the majority of these contain timely and helpful articles. Every operator should have a representative catalog and manufacturer's bulletins to cover each unit and auxiliaries in his plant. Visits by a high type of salesmen should always be a source of information.

**Training Programs.** Training opportunities are offered through annual short courses and, in some states, by a traveling vocational school. The short course is generally given at the state university, utilizing its technical faculty and facilities; departmental officials and other operators also contribute to the program. The traveling school is conducted by an instructor who holds day or night classes for a short period at convenient centers throughout the state and makes plant visits to offer advice on operating problems and to coach the operators. Certificates of attendance are sometimes issued to operators who enroll at these courses. Both types of school should be actively encouraged by the fullest attendance and interest because for the average operator, the school programs provide the highest rate of educational returns.

Training programs are generally planned to aid operators in taking their examinations for various types of licenses or certificates. In some states, licenses are required by law for all water plant operators; in other states, licenses are encouraged by a grading system applied to evaluate the safety of the public water supply. At the present time in most states the examination of operators is voluntary, and is impelled solely by the

operator's own interest in establishing his work upon a high plane. The examining committee is composed usually of representatives of the State Department of Health, the traveling school, the state university, and two representatives from the water operators' association.

**Association Membership.** Two or three types of association membership are generally open to water supply operators; these are in the American Water Works Association, the Section of the American Water Works Association in which the supply is located, and the State Conference on Water Supply and Sewerage, or its equivalent.

The American Water Works Association is a national organization. It holds annual conventions, issues a ranking monthly journal which authoritatively covers all aspects of water supply, and maintains active representation in official government circles to gather regulations issued by various emergency bureaus and to represent the water supply industry. Attendance at its conventions, aside from the formal program, offers opportunity for operators from widely different geographical sections to exchange experiences and viewpoints. An extensive exhibit of manufacturers' products enables the registrants to view the latest in equipment.

Various sections of the American Water Works Association, affiliated with the national body, also hold an annual conference and may publish a short monthly journal or annual proceedings.

The State Conference on Water Supply and Sewerage or an equivalent body is a state-wide organization of operators. Its activities include administration of the Certification or Licensing Program, participation in planning an annual short course, sponsorship of the traveling school where operative, and holding of an annual meeting. As this is the operators' own organization, their vigorous support should be forthcoming. Improvement of the operators' status will come largely through the efforts of this body.

## CHAPTER 23

### USEFUL LITERATURE

#### BOOKLETS

THE booklets listed below are mainly from manufacturers and public agencies. These materials are free on request, except where noted.

| TOPIC     | TITLE  | SOURCE  |
|-----------|--|---|
| Wells     | <i>Ground Water Supplies</i> , Supplement No. 124 to the <i>Public Health Reports</i> .                            | Superintendent of Documents, Government Printing Office, Washington, D. C. 5¢   |
|           | <i>Sanitation Manual for Public Ground Water Supplies</i> , Reprint No. 2539 to the <i>Public Health Reports</i> . | Superintendent of Documents, Government Printing Office, Washington, D. C. 10¢  |
| Plant     | Reference and Data Section, <i>Water Works &amp; Sewerage</i> .  | Water Works & Sewerage, 330 So. Wells Street, Chicago, Ill. (with subscription) |
|           | <i>The Manual of Water Works Equipment and Materials</i> .   | Public Works Magazine, 310 East 45th St., New York, N. Y. \$1.00                |
|           | <i>Water Supply Control</i> , Bulletin No. 22.   | Division of Sanitation, New York State Dept. of Health, Albany, N. Y. 50¢       |
| Treatment | <i>Water Supply and Treatment</i> , Charles P. Hoover.   | National Lime Association, Washington, D. C.                                    |
|           | <i>Alkalies and Chlorine in the Treatment of Municipal and Industrial Water</i> , Bulletin No. 8.                  | Solvay Sales Corporation, 40 Rector St., New York, N. Y.                        |

| TOPIC                   | TITLE   | SOURCE   |
|-------------------------|---|--|
| Treatment, <i>cont.</i> | <i>Water and Sewage Chemistry and Chemicals.</i>                                      | General Chemical Company,<br>40 Rector St.,<br>New York, N. Y.   |
|                         | <i>Ferrisul.</i>  | Merrimac Chemical Co.,<br>Boston, Mass.  |
|                         | <i>Jar Test Evaluation of Silica Coagulant Aids.</i>                                  | The Philadelphia Quartz Co.,<br>121 S. Third St.,<br>Philadelphia, Pa.   |
|                         | <i>Data Book.</i>   | The Permutit Co.,<br>330 West 42nd St.,<br>New York, N. Y.   |
| Chlorine                | <i>Chlorine.</i>  | Pennsylvania Salt Mfg. Co.,<br>Philadelphia, Penna.  |
|                         | Various bulletins.  | Wallace & Tiernan, Inc.,<br>Newark, N. J.  |
| Algae                   | <i>The Use of Copper Sulfates in Control of Microscopic Organisms,</i> Frank E. Hale. | Nichols Copper Co.,<br>25 Broad St.,<br>New York, N. Y.  |
| Odors                   | <i>Taste and Odor Control in Water Purification.</i>                                  | Industrial Chemical Sales,<br>Division West Virginia<br>Pulp & Paper Co.,<br>230 Park Ave.,<br>New York, N. Y. |
| Analysis                | <i>Water Analysis,</i> Bulletin No. 11.   | Solvay Sales Corp.,<br>40 Rector St.,<br>New York, N. Y.   |
|                         | <i>Water Handbook.</i>  | W. H. & L. D. Betz,<br>Frankford,<br>Philadelphia, Penna. 50¢  |
|                         | <i>The A, B, C of pH Control.</i>   | LaMotte Chemical Co.,<br>Towson,<br>Baltimore, Md.   |
|                         | <i>Modern pH and Chlorine Control.</i>  | W. A. Taylor & Co.,<br>7300 York Road,<br>Baltimore, Md.   |
| Bacteriology            | <i>Dehydrated Culture Media and Reagents,</i> 6th Edition, 1939.                      | Difco Laboratories,<br>Detroit, Mich.  |
| Motors                  | <i>Catechism of Electrical Machinery,</i> Bulletin E, 100 C.                          | Fairbanks, Morse & Co.,<br>Chicago, Ill.   |

| TOPIC                | TITLE   | SOURCE  |
|----------------------|---|---|
| Motors, <i>Cont.</i> | <i>How to Care for Motors.</i>  | General Electric,<br>Schenectady, N. Y.                                 |
|                      | <i>Handbook No. 143.</i>  | Ideal Commutator Dresser<br>Co.,<br>Sycamore, Ill.                      |
| Pumps                | <i>How to Recondition Worn Pump Shafts and Rods.</i>  | The International Nickel<br>Co.,<br>67 Wall St.,<br>New York, N. Y.     |
|                      | <i>Standards of the Hydraulic Institute, Section B. Centrifugal Pump, 50¢; Section E. Deep Well Turbine Pump, 25¢; Section F. Test Code, 50¢.</i> | Hydraulic Institute,<br>90 West St.,<br>New York, N. Y.                 |
|                      | <i>Pump Handbook.</i>   | Pomona Pump Co.,<br>Pomona, Cal.  |
|                      | <i>Pump Data.</i>   | Economy Pumping Mach.<br>Co.,<br>Chicago, Ill.                          |
|                      |   |   |
| Piping               | <i>Handbook of Cast Iron Pipe.</i>  | Cast Iron Pipe Research<br>Association,<br>Chicago, Ill.                |
|                      | <i>Transite Pressure Pipe, DS Series 328.</i>   | Johns Manville,<br>22 East 40th St.,<br>New York, N. Y.                 |
|                      | <i>Handbook on Hydraulics, Bulletin No. 21.</i>   | National Tube Co.,<br>Pittsburgh, Pa.                                   |
|                      | <i>Saran Pipe and Tubing.</i>   | Dow Chemical Company,<br>Midland, Michigan                              |
|                      | <i>Piping Pointers.</i>   | Crane Company,<br>836 South Michigan Ave.,<br>Chicago 5, Ill.           |
|                      | <i>Water Supply for Municipal Fire Fighting, Bulletin No. 116.</i>  | National Board of Fire Underwriters,<br>85 John St.,<br>New York, N. Y. |
|                      | <i>Universal Calculator for Flow of Water in Pipes.</i>   | Grinnell Co.,<br>Providence 1, R. I.                                    |



| TOPIC             | TITLE  | SOURCE   |
|-------------------|--|--|
| Meters            | <i>An Outline of Water Meter Practice</i> , Henry Horandt.   | Neptune Meter Co.,<br>50 West 50th St.,<br>New York, N. Y.   |
|                   | <i>Rotameter</i> , Bulletin No. 10-A.  | Fischer and Porter Co.,<br>Hatboro, Pennsylvania   |
| Cross Connections | <i>Cross Connections in Plumbing and Water Supply Systems</i> .  | Bureau of Plumbing and Domestic Sanitary Engineering,<br>Wisconsin State Board of Health,<br>Madison, Wis. |
|                   | <i>Interconnector</i> .  | Industrial Interconnector Co.,<br>2150 Niagara St.,<br>Buffalo 7, N. Y.                                    |
| Sanitation        | <i>Manual of Water Supply Sanitation</i> (in Sections).  | Division of Sanitation,<br>Minnesota Department of Health,<br>Minneapolis, Minn.                           |
|                   | <i>Public Health Service Drinking Water Standards and Manual of Water Sanitation Practice</i> , Reprint No. 2440 from the Public Health Reports. | U. S. Public Health Service,<br>Washington, D. C.  |
|                   | <i>Water Works Engineering in Disaster</i> , OCD Publication 2022.   | Office of Civilian Defense,<br>Washington 25, D. C.  |
|                   | <i>Protection and Maintenance of Public Water Supplies under War Conditions</i> , OCD Publication 3030.  | Office of Civilian Defense,<br>Washington 25, D. C.  |
| Fire Protection   | <i>Standard Schedule for Grading Cities and Towns of the United States with Reference to Their Fire Defenses and Physical Conditions</i> .       | National Board of Fire Underwriters,<br>85 John St.,<br>New York, N. Y.                                    |

## TEXTBOOKS

(Many publishers allow a 10-day free examination period for the reader to judge the value and applicability of their books.)

|   |  |        |
|---|--|--------|
| <i>Water Works Practice—Manual of the A.W.W.A.</i> (Out of Print; Used Copies Resold).  | American Water Works Association,<br>500 Fifth Ave.,<br>New York, N. Y.  |        |
| <i>Manual of Water Quality and Treatment.</i>   | American Water Works Association,<br>500 Fifth Ave.,<br>New York, N. Y.  | \$3.00 |
| <i>Water Supply and Sewerage</i> , E. W. Steel, 653 pp.   | McGraw-Hill Book Co.,<br>New York, N. Y.                                 | \$5.00 |
| <i>Handbook of Hydraulics</i> , H. W. King.   | McGraw-Hill Book Co.,<br>New York, N. Y.                                 | \$4.00 |
| <i>Elements of Hydraulics</i> , Mansfield Merriman.   | John Wiley and Sons Co.,<br>New York, N. Y.                              | \$1.50 |
| <i>Standard Methods for Analysis of Water and Sewerage</i> , 8th edition, 1936.   | American Public Health Association,<br>1790 Broadway,<br>New York, N. Y. | \$2.50 |
| <i>Laboratory Manual for Chemical and Bacterial Analysis of Water and Sewage</i> , F. R. Theroux, E. F. Eldridge and W. L. Mallman. | McGraw-Hill Book Co.,<br>New York, N. Y.                                 | \$2.50 |
| <i>Smith's College Chemistry</i> , Revised by James Kendall.  | The Century Co.,<br>New York, N. Y.                                      | \$3.75 |
| <i>Microbiology of Water and Sewage</i> , P. L. Gainey, 283 pp. mimeoprint.   | Burgess Publishing Co.,<br>426 S 6th St.,<br>Minneapolis, Minn.          | \$3.00 |
| <i>Whipple's Microscopy of Drinking Water</i> , Revised by G. M. Fair and M. C. Whipple.  | John Wiley & Sons Co.,<br>New York, N. Y.                                | \$7.00 |
| <i>Bacteriology</i> , E. D. Buchanan and R. E. Buchanan.  | The Macmillan Company,<br>New York, N. Y.                                | \$3.50 |
| <i>Principles and Practice of Bacteriology</i> , (College Outline Series) Revised by Bryan and Bryan.                               | Barnes & Noble, Inc.,<br>New York, N. Y.                                 | \$1.25 |

## PERIODICALS

|  |   |
|--|---|
| <i>Water Works &amp; Sewerage.</i>                         | Gillette Publishing Co.,<br>330 S. Wells St.,<br>Chicago, Ill.  |
| <i>Journal of the American Water Works Association.</i>    | American Water Works Association,<br>500 Fifth Ave.,<br>New York, N. Y.                                     |
| <i>Journal of the New England Water Works Association.</i> | New England Water Works Association,<br>613 Statler Bldg.,<br>Boston, Mass.                                 |
| Individual Sectional Journals.                             | Sectional Groups of the American Water Works Association.   |
| <i>Water Works Engineering.</i>                            | Case-Sheppard-Mann Publishing Co.,<br>24 West 40th St.,<br>New York, N. Y.                                  |
| <i>Public Works.</i>                                       | Public Works Magazine,<br>310 East 45th St.,<br>New York, N. Y.   |
| <i>Taste and Odor Journal.</i>                             | Industrial Chemical Sales,<br>Division West Virginia Pulp & Paper Co.,<br>237 Park Ave.,<br>New York, N. Y. |
| <i>The Johnson National Drillers' Journal.</i>             | Edward E. Johnson, Inc.,<br>St. Paul 4, Minnesota.  |

## CHAPTER 24

# USEFUL WATER PLANT DATA AND FACTORS

TABLE 20

### Useful Water Plant Data and Factors

| LENGTH            |                         |                           |
|-------------------|-------------------------|---------------------------|
| 1 yard (yd.)      | = 3 feet (ft.)          | = 36 inches (in.)         |
| 1 mile (mi.)      | = 1760 yards (yd.)      | = 5,280 feet (ft.)        |
| 1 meter (m.)      | = 100 centimeters (cm.) | = 1,000 millimeters (mm.) |
| 1 kilometer (km.) | = 1,000 meters (m.)     |                           |
|                   | 1 centimeter (cm.)      | = 0.3937 inches (in.)     |
|                   | 1 inch (in.)            | = 2.54 centimeters (cm.)  |

|                         |                                       | AREA                                     |
|-------------------------|---------------------------------------|--|
|                         |                                       |  |
| 1 square foot (sq. ft.) | = 144 square inches (sq. in.)         |  |
| 1 square yard (sq. yd.) | = 9 square feet (sq. ft.)             |  |
| 1 acre (A.)             | = 43,560 square feet (sq. ft.)        |  |
| 1 square meter (sq. m.) | = 10,000 square centimeters (sq. cm.) |  |
|                         |                                       | = 1,000,000 square millimeters (sq. mm.) |
|                         | 1 square inch (sq. in.)               | = 6.475 square centimeters (sq. cm.)     |

|                               |   |         |        |             | VOLUME |
|-------------------------------|---|---------|--------|-------------|--------|
|                               |   |         |        |             |        |
|                               | Cubic   |         | Fluid  |             |        |
|                               | Feet  | Gallons | Ounces | Milliliters |        |
| 1.0 cubic foot (cu. ft.)      | 1.0   | 7.4805  | 960.0  | 28,317.0    |        |
| 1.0 gallon (gal.)             | 0.1337  | 1.0     | 128.0  | 3,785.4     |        |
| 1.0 fluid ounce (fl. oz.)     | 0.000103  | 0.0078  | 1.0    | 29.57       |        |
| 1.0 milliliter (ml.)          | 0.000035  | 0.00026 | 0.0339 | 1.0         |        |
| 1 cubic foot (cu. ft.)        | = 1728 cubic inches (cu. in.)   |         |        |             |        |
| 1 cubic yard (cu. yd.)        | = 27 cubic feet (cu. ft.)   |         |        |             |        |
| 1 U. S. gallon (gal.)         | = 231 cubic inches (cu. in.) = 0.833 English (Imperial) gallons (Imp. gal.)         |         |        |             |        |
| 1 Imperial gallon (Imp. gal.) | = 1.2 U. S. gallons (gal.)  |         |        |             |        |
| 1 liter (l.)                  | = 1,000 milliliters (ml.); milliliters are sometimes called cubic centimeters (cc.) |         |        |             |        |
|                               | 1 liter (l.) = 1.06 quarts (qt.)  |         |        |             |        |
|                               | 1 quart (qt.) = 0.945 liters (l.)   |         |        |             |        |
|                               | = 945 milliliters (ml.)   |         |        |             |        |

## WEIGHT

|                 | Pounds   | Ounces  | Grains | Grams  |
|-----------------|----------|---------|--------|--------|
| 1.0 pound (lb.) | 1.0      | 16.0    | 7,000  | 453.6  |
| 1.0 ounce (oz.) | 0.0625   | 1.0     | 437.5  | 28.35  |
| 1.0 grain (gr.) | 0.00014  | 0.0023  | 1.0    | 0.0648 |
| 1.0 gram (g.)   | 0.002205 | 0.03527 | 15.432 | 1.0    |

1 ton (T.) = 2,000 pounds (lb.)

1 kilogram (kg.) = 1,000 grams (g.)

Density of water = 1.00

Density of mercury = 13.56

1 U. S. gallon (231 cu. in.) of water weighs = 8.345 pounds (lb.)

1 English gallon (Imp. gal.) of water weighs = 10.00 pounds (lb.)

1 cubic foot (cu. ft.) of water at 39.1°C. weighs = 62.425 pounds (lb.)

1 cubic foot (cu. ft.) of water at 62°F. weighs = 62.375 pounds (lb.)

## CONCENTRATION UNITS

|  | Pounds<br>per<br>Million<br>Gallons<br>(lb./MG) | Parts<br>per<br>Million<br>(p.p.m.) | Grains<br>per<br>Gallon<br>(g.p.g.) |
|--|---|-------------------------------------|-------------------------------------|
| 1.0 pound per million gallons (lb./MG)       | 1.0   | 0.1198                              | 0.007                               |
| 1.0 pound per 1,000 gallons (lb./1,000 gal.) | 1,000   | 119.8                               | 7.0                                 |
| 1.0 part per million (p.p.m.)                | 8.345   | 1.0                                 | 0.0584                              |
| 1.0 grain per gallon (g.p.g.)                | 142.857   | 17.118                              | 1.0                                 |

1 part per million (p.p.m.) = 1 milligram per liter (mg./l.)

## FLOW RATE

|  | Cubic Feet<br>per Second<br>(c.f.s.) | Million<br>Gallons<br>per Day<br>(MGD) | Gallons<br>per<br>Minute<br>(g.p.m.) |
|--|--------------------------------------|--|--------------------------------------|
| 1 cubic foot per second (c.f.s., cusec.,<br>or cu. ft./sec.) | 1.0                                  | 0.646316                               | 448.83                               |
| 1 million gallons per day (MGD)                              | 1.54723                              | 1.0                                    | 694.4                                |
| 1 gallon per minute (g.p.m.)                                 | 0.002228                             | 0.00144                                | 1.0                                  |

1 cubic foot per second (c.f.s.) = 646,316 gallons per day  
(g.p.d.)

1 gallon per minute (g.p.m.) = 63.1 milliliters per second  
(ml./sec.)

125 million gallons per acre per day (MGAD)

= 2 gallons per square foot per minute (gal./sq. ft./min.)

= 3.2 inches rise per minute (in./min.)

= 1.0 times filter rate (normal)

1 day = 24 hours = 1,440 minutes = 86,400 seconds

## FEED RATE

|                               |                                     |
|-------------------------------|-------------------------------------|
| 1 ounce per minute (oz./min.) | = 90 pound per day (lb./da.)        |
| 1 pound per minute (lb./min.) | = 1,440 pounds per day (lb./da.)    |
| 1 pound per day (lb./da.)     | = 0.3150 grams per minute (g./min.) |
| 1 gram per minute (g./min.)   | = 0.1322 pounds per hour (lb./hr.)  |
|                               | = 3.177 pounds per day (lb./da.)    |

## JAR TEST DOSAGE

| Volume of Jar   | Treatment given by<br>1 ml. of Stock Solution | Concentration of<br>Stock Solution<br>grams/liter |
|-----------------|---|---|
| 1 gallon (gal.) | { 1 part per million (p.p.m.)                 | 3.78  |
|                 | { 1 pound per million gallons (lb./MG)        | 0.454   |
|                 | { 1 grain per gallon (g.p.g.)                 | 64.7  |
| 1 liter (l.)    | { 1 part per million (p.p.m.)                 | 1.00  |
|                 | { 1 pound per million gallons (lb./MG)        | 0.120   |
|                 | { 1 grain per gallon (g.p.g.)                 | 17.1  |

## PRESSURE

|   | Pounds per<br>Square Inch<br>(psi.) | Feet of<br>Water<br>(ft. water) | Inches of<br>Mercury<br>(in. Hg.) |
|---|-------------------------------------|---------------------------------|-----------------------------------|
| 1.0 pound per square inch<br>(lb./sq. in. or psi.)    | 1.0                                 | 2.307                           | 2.036                             |
| 1.0 feet of water (ft. water)                         | 0.4335                              | 1.0                             | 0.883                             |
| 1.0 inch of mercury (in. Hg.)<br>(open end manometer) | 0.4912                              | 1.133                           | 1.0                               |

1 inch of mercury (in. Hg.) = 1.05 feet of water (ft. water)  
(Differential manometer; both arms  
under water)

## ENERGY

|                     |   |
|---------------------|---|
| 1 horse power (HP.) | = 550 foot-pounds per second (ft.-lb./sec.)         |
|                     | = 33,000 foot-pounds per minute<br>(ft.-lb./min.)   |
|                     | = 0.746 kilowatts (kw.)                             |
|                     | = 3,960 gallons per minute against 1-foot<br>head   |
| 1 kilowatt (kw.)    | = 1.341 horse power (HP.)                           |
|                     | = 5,310 gallons per minute against a<br>1-foot head |

|                              |  |
|------------------------------|--|
| 1 horse power-hour (HP. hr.) | = $1.98 \times 10^6$ foot-pounds (ft. lb.)                 |
|                              | = 0.746 kilowatt hours (kw. hr.)                           |
|                              | = 237,600 gallons of water pumped<br>against a 1-foot head |
| 1 kilowatt hour (kw. hr.)    | = 1.341 horse power-hour (HP. hr.)                         |
|                              | = 318,700 gallons of water pumped<br>against a 1-foot head |

$$\text{Efficiency \%} = \frac{\text{gallons per minute (g.p.m.)} \times \text{head (ft. water)}}{53.1 \times \text{kilowatts (kw.)}}$$

Pumping cost (approximate) per 1000 gallons against a 100-foot head  
(wire to water efficiency assumed to be 62.4%),  
cents per thousand gallons ( $\$/1000$  gal.) = power cost ( $\$/\text{kw. hr.}$ )  $\times$  0.5

#### HYDRAULIC FORMULAS

(See Chapter 17)

Flow in gallons per minute (g.p.m.) through various devices:

Sharp-edged circular orifice,

$$Q \text{ (g.p.m.)} = 12.0 D_{\text{inches}}^2 \sqrt{h_1 - h_{2\text{ft. water}}}$$

Fire hydrant nozzle,

$$Q \text{ (g.p.m.)} = 27 D_{\text{inches}}^2 \sqrt{\text{Pressure}_{\text{psi}}}$$

Venturi meter,

$$Q \text{ (g.p.m.)} = 2821 C \sqrt{\frac{d_1^4 d_2^4}{d_1^4 - d_2^4}} \sqrt{h_1 - h_{2\text{ft. water}}}$$

Pitot tube,  $Q \text{ (g.p.m.)} = 16.26 D_{\text{inches}}^2 \sqrt{h_{\text{ft. water}}}$

Sharp-edged rectangular weir,

$$Q \text{ (g.p.m.)}, \text{ per foot of width} = 35.94 H_{\text{inches}}^{3/2}$$

#### TABLE 21

Approximate Weight per Cubic Foot of Various  
Water Plant Materials

| Material          | Pounds per<br>Cubic Foot |
|-------------------|--------------------------|
| <i>Structural</i> |                          |
| Coke              | 23- 32                   |
| Limestone         | 116-158                  |
| Gravel            | 98                       |
| Sand              | 100                      |
| Anthraflit        | 47                       |
| Cement            | 92                       |

TABLE 21—Continued

Approximate Weight per Cubic Foot of Various  
Water Plant Materials

| Material  | Pounds per<br>Cubic Foot |
|---|--------------------------|
| <i>Treatment Chemicals</i>                      |                          |
| Quicklime (lumps)                               | 53- 64                   |
| Hydrated lime                                   | 36                       |
| Copperas (ferrous sulfate)                      | 66                       |
| Alum  | 60                       |
| Ferric sulfate                                  | 74                       |
| Activated carbon                                | 13.5                     |
| Soda ash (sodium carbonate)                     | 88                       |
| Sodium aluminate (powdered)                     | 38                       |
| Caustic soda                                    | 80                       |
| Zeolites  | { synthetic 50           |
|   | { natural greensand 85   |
| Salt (sodium chloride)                          | 77                       |
| HTH (calcium hypochlorite)                      | 48                       |
| Bluestone (copper sulfate)                      | 82                       |
| Sodium silicate (42° Beaumé liquid)             | 117                      |
| Sodium hexametaphosphate (flakes)               | 37                       |
| Sodium hexametaphosphate (micromet<br>granules) | 75                       |



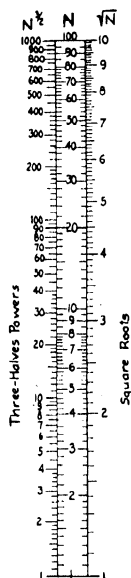


FIGURE 49

Scales for Three-Halves Powers and Square Roots of Numbers from 1 to 100

These scales may also be used for decimals, considering 100 on the central scales to denote 100/100 or unity; on the three-halves powers scale the numerals will be in thousandths and on the square root scale the numerals will be in tenths. Thus  $0.60^{3/2} = 0.470$ ;  $\sqrt{0.60} = 0.775$ .



FIGURE 50

Comparison of Centigrade and Fahrenheit Thermometer Scales;  
 $^{\circ}\text{F.} = (^{\circ}\text{C.} \times 1.8) + 32$

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